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<p>(54) Title: FLK-1 IS A RECEPTOR FOR VASCULAR ENDOTHELIAL GROWTH FACTOR</p>			
<p>FLK-1 866 ILIHICHHLNVNLLGACTKPGPLMVIVEFSKFGNLSTYLRGKRNEFVPYKSKGARFRQ KDR _____ C-D-S-T _____ TKR-C _____ C _____ S</p>			
<p>FLK-1 926 GKDYVGELSVDLKRRLDSITSSOSSASSGFVEEKSLSDVEEEASEEELYKDFLTLEHLIC KDR _____ AIP _____ P-D _____ TKR-C _____</p>			
<p>FLK-1 986 YSFQVAKGMELASRKCIHRDLAARNILLSEKNVKICDFGLARDIYKDPDYVRKGARL KDR _____ TKR-C _____</p>			
<p>(57) Abstract</p> <p>The present invention relates to the use of ligands for the Flk-1 receptor for the modulation of angiogenesis and vasculogenesis. The invention is based, in part, on the demonstration that Flk-1 tyrosine kinase receptor expression is associated with endothelial cells and the identification of vascular endothelial growth factor (VEGF) as the high affinity ligand of Flk-1. These results indicate a major role for Flk-1 in the signaling system during vasculogenesis and angiogenesis. Engineering of host cells that express Flk-1 and the uses of expressed Flk-1 to evaluate and screen for drugs and analogs of VEGF involved in Flk-1 modulation by either agonist or antagonist activities is described. The invention also relates to the use of FLK-1 ligands, including VEGF agonists and antagonists, in the treatment of disorders, including cancer, by modulating vasculogenesis and angiogenesis.</p>			

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Flk-1 IS A RECEPTOR FOR VASCULAR
ENDOTHELIAL GROWTH FACTOR

1. INTRODUCTION

5 The present invention relates to the use of ligands for the FLK-1 receptor for the modulation of angiogenesis and vasculogenesis. The invention is based, in part, on the demonstration that Flk-1 tyrosine kinase receptor expression is associated with endothelial cells and the 10 identification of vascular endothelial growth factor (VEGF) as the high affinity ligand of Flk-1. These results indicate a major role for Flk-1 in the signaling system during vasculogenesis and angiogenesis.

15 Engineering of host cells that express Flk-1 and the uses of expressed Flk-1 to evaluate and screen for drugs and analogs of VEGF involved in Flk-1 modulation by either agonist or antagonist activities is described.

20 The invention also relates to the use of FLK-1 ligands, including VEGF agonists and antagonists, in the treatment of disorders, including cancer, by modulating vasculogenesis and angiogenesis.

2. BACKGROUND OF THE INVENTION

25 Receptor tyrosine kinases comprise a large family of transmembrane receptors for polypeptide growth factors with diverse biological activities. Their intrinsic tyrosine kinase function is activated upon ligand binding, which results in phosphorylation of the receptor and multiple cellular substrates, and subsequently in a 30 variety of cellular responses (Ullrich A. and Schlessinger, J., 1990, Cell 61:203-212).

35 A receptor tyrosine kinase cDNA, designated fetal liver kinase 1 (Flk-1), was cloned from mouse cell populations enriched for hematopoietic stem and progenitor cells. The receptor was suggested to be involved in hematopoietic stem cell renewal (Matthews

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et al., 1991, Proc. Natl. Acad. Sci. USA 88:9026-9030).

Sequence analysis of the Flk-1 clone revealed considerable homology with the c-Kit subfamily of receptor kinases and in particular to the Flt gene

5 product. These receptors all have in common an extracellular domain containing immunoglobulin-like structures.

The formation and spreading of blood vessels, or vasculogenesis and angiogenesis, respectively, play

10 important roles in a variety of physiological processes such as embryonic development, wound healing, organ regeneration and female reproductive processes such as follicle development in the corpus luteum during ovulation and placental growth after pregnancy.

15 Uncontrolled angiogenesis can be pathological such as in the growth of solid tumors that rely on vascularization for growth.

Angiogenesis involves the proliferation, migration and infiltration of vascular endothelial cells, and is

20 likely to be regulated by polypeptide growth factors.

Several polypeptides with in vitro endothelial cell growth promoting activity have been identified. Examples include acidic and basic fibroblastic growth factor, vascular endothelial growth factor and placental growth

25 factor. Although four distinct receptors for the different members of the FGF family have been characterized, none of these have as yet been reported to be expressed in blood vessels in vivo.

While the FGFs appear to be mitogens for a large 30 number of different cell types, VEGF has recently been reported to be an endothelial cell specific mitogen (Ferrara, N. and Henzel, W.J., 1989, Biochem. Biophys. Res. Comm. 161:851-858). Recently, the fms-like tyrosine receptor, flt, was shown to have affinity for VEGF 35 (DeVries, C. et al. , 1992, Science 255:989-991).

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3. SUMMARY OF THE INVENTION

The present invention relates to the use of ligands for the Flk-1 receptor for the modulation of angiogenesis and vasculogenesis. The present invention is based, in part, on the discovery that the Flk-1 tyrosine kinase receptor is expressed on the surface of endothelial cells and the identification of vascular endothelial growth factor (VEGF) as the high affinity ligand of Flk-1. The role of endothelial cell proliferation and migration during angiogenesis and vasculogenesis indicate an important role for Flk-1 in these processes. The invention is described by way of example for the murine Flk-1, however, the principles may be applied to other species including humans.

Pharmaceutical reagents designed to inhibit the Flk-1/VEGF interaction may be useful in inhibition of tumor growth. VEGF and/or VEGF agonists may be used to promote wound healing. The invention relates to expression systems designed to produce Flk-1 protein and/or cell lines which express the Flk-1 receptor. Expression of soluble recombinant Flk-1 protein may be used to screen peptide libraries for molecules that inhibit the Flk-1/VEGF interaction. Engineered cell lines expressing Flk-1 on their surface may be advantageously used to screen and identify VEGF agonists and antagonists.

4. BRIEF DESCRIPTION OF THE FIGURES

FIG. 1. Comparison of the Flk-1 amino acid sequence with related RTKs. Amino acid sequence comparison of Flk-1 with human KDR and rat TKr-C. A section of the sequence which is known for all three receptors is compared and only differences to the Flk-1 sequence are shown.

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FIG. 2. Northern blot analysis of Flk-1 gene expression. (A) Expression of Flk-1 RNA in day 9.5 to day 18.5 mouse embryos. Samples (10 μ g) of total RNA from whole mouse embryos were analyzed in each lane. 5 Positions of 28S and 18S ribosomal RNAs are marked. (B) Expression of Flk-1 mRNA in postnatal day 4 and adult brain in comparison with capillary fragments from postnatal day 4 brain. 1 μ g of poly (A⁺) RNA was loaded on each lane. The 5' 2619 bp of the Flk-1 cDNA were used 10 as a probe. Control hybridization with a GAPDH cDNA probe is shown in the lower panel.

FIG. 3. Abundant Flk-1 gene expression in embryonic tissues. *In situ* hybridization analysis of Flk-1 expression in day 14.5 mouse embryo. (A) Bright 15 field illumination of a parasagittal section through the whole embryo hybridized with a ³⁵S-labeled antisense probe (5' 2619 bp). (B) Dark field illumination of the same section. (C) Control hybridization of an adjacent section with a sense probe. Abbreviations: Ao, aorta; 20 At, atrium; L, lung; Li, liver; Ma, mandible; Mn, meninges; Ms, mesencephalon; T, telencephalon; V, ventricle; Vt, vertebrae.

FIG. 4. Expression of Flk-1 RNA in embryonic organs is restricted to specific cells. Expression of 25 Flk-1 RNA in a day 14.5 mouse embryo at higher magnification. (A) The heart region was probed with a ³⁵S-labeled antisense probe. (B) Adjacent section hybridized with the sense probe. (C) Part of the aorta wall shown on the cellular level. The endothelial cell- 30 layer is indicated by an arrow. (D) The lung, probed with the Flk-1 antisense probe. (E) Control hybridization of an adjacent section hybridized with the sense probe. Abbreviations: At, atrium; B, bronchus; Ed, endothelial cell layer; En, endocardium; L, lung, Li,

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liver; Lu, lumina of the aorta; Ml, muscular; My, myocardium.

FIG. 5. Flk-1 gene expression in the brain of the developing mouse. *In situ* hybridization analysis of Flk-1 gene expression in the brain at different developmental stages. All sections were probed with the Flk-1 antisense probe. (A) Sagittal section of the telencephalon of a day 11.5 mouse embryo. A single blood vessel expressing Flk-1, which sprouts from the meninges into the neuroectoderm, is indicated by an arrow. (B) Sagittal sections of the brain of embryo day 14.5 and (C) of postnatal day 4. Shown are regions of the mesencephalon. Branching capillaries and blood vessels expressing Flk-1 are indicated by an arrow. (D) Sagittal section of an adult brain; a region of the mesencephalon is shown. Cells expressing Flk-1 are indicated by an arrow. Abbreviations: M, meninges; V, ventricle;

FIG. 6. Expression of Flk-1 in the choroid plexus of adult brain. (A) Darkfield illumination of the choroid plexus of an adult mouse brain hybridized with Flk-1 antisense probe. (B) Choroid plexus shown at a higher magnification. Arrows indicate single cells, which show strong expression of Flk-1. Abbreviations: CP, choroid plexus; E, ependyme; Ep, epithelial cells; V, ventricle.

FIG. 7. Flk-1 is expressed in the glomeruli of the kidney. (A) Parasagittal section of a 4-day postnatal kidney, hybridized with the Flk-1 antisense probe. Hybridization signal accumulates in the glomeruli, as indicated by arrowheads. (B) Control hybridization of an adjacent section with the sense probe. (C) Sagittal section of an adult kidney probed with Flk-1. Arrowheads indicate glomeruli. (D) Glomerulus of an adult kidney at a higher magnification. The arrows in (A) and (D)

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indicate cells aligned in strands in the juxtaglomerular region expressing Flk-1.

FIG. 8. *In situ* hybridization analysis of Flk-1 expression in early embryos and extraembryonic tissues.

5 (A) Sagittal section of a day 8.5 mouse embryo in the maternal deciduum probed with Flk-1. (B) Higher magnification of the deciduum. Arrowheads indicate the endothelium of maternal blood vessels strongly expressing Flk-1 RNA. (C) High magnification of the yolk sac and
10 the trophectoderm of a day 9.5 mouse embryo. (D) High magnification of a blood island. Abbreviations:
A, allantois; Bi, blood island; Bv, maternal blood vessel; D, deciduum; En, endodermal layer of yolk sac; M, mesenchyme; Ms, mesodermal layer of yolk sac; NF, 15 neural fold; T, trophoblast; Y, yolk sac.

FIG. 9. Flk-1 is a receptor for VEGF. (A) Cross linking of ¹²⁵I-VEGF to COS cells transiently expressing the Flk-1 receptor and control cells were incubated with ¹²⁵I-VEGF at 4°C overnight, then washed twice with
20 phosphate buffered saline (PBS) and exposed to 0.5 mM of the cross linking agent DSS in PBS for 1 hour at 4°C. The cells were lysed, Flk-1 receptor immunoprecipitated, and analyzed by polyacrylamide gel electrophoresis followed by autoradiography. Molecular size markers are
25 indicated in kilodaltons. (B) Specific binding of ¹²⁵I-VEGF to COS cells expressing Flk-1. COS cells transiently expressing Flk-1 were removed from the plate and resuspended in binding medium (DMEM, 25 mM Hepes, 0.15% gelatin). Binding was performed at 15°C for 90
30 minutes in a total volume of 0.5 ml containing 2x10⁵ cells, 15,000 cpm ¹²⁵I-VEGF, and the indicated concentrations of unlabeled ligand. The cells were washed twice with PBS / 0.1% BSA and counted in a gamma counter.

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FIG. 10. VEGF-induced autophosphorylation of Flk-1. COS cells transiently expressing Flk-1 receptor and control cells were starved for 24 hours in DMEM containing 0.5% fetal calf serum and then stimulated with 5 VEGF for 10 minutes as indicated. The cells were solubilized, Flk-1 receptor immunoprecipitated with a polyclonal antibody against its C-terminus, separated by polyacrylamide gel electrophoresis, and transferred to nitrocellulose. The blot was probed with 10 antiphosphotyrosine antibodies (5B2). The protein bands were visualized by using a horseradish-peroxidase coupled secondary antibody and BCL™ (Amersham) detection assay.

FIG. 11. Nucleotide Sequence of Murine Flk-1.

FIG. 12. Plasmid Maps of retroviral vector

15 constructs. pLXSN Flk-1 TM Cl.1 and pLXSN Flk-1 TM cl.3 contain Flk-1 amino acids 1 through 806. pNTK-cfms-TM contains the 541 N-terminal amino acids of c-fms.

FIG. 13. Inhibition of C6 glioblastoma tumor growth by transdominant-negative inhibition of Flk-1. C6 cells 20 were implanted either alone or coimplanted with virus-producing cells. Cell numbers are as indicated in each panel. Two different virus-producing cell lines were used: one expressing the Flk-1 TM (transdominant-negative) mutant and one expressing a transdominant-negative c-fms mutant (c-fms TM) as a control. Beginning 25 at the time when the first tumors appeared, tumor volumes were measured every 2 to 3 days to obtain a growth curve. Each group is represented by four mice.

FIG. 14. Inhibition of C6 glioblastoma tumor growth 30 by transdominant-negative inhibition of Flk-1. C6 cells were implanted either alone or coimplanted with virus-producing cells. Cell numbers are as indicated in each panel. Two different virus-producing cell lines were used: one expressing the Flk-1 TM (transdominant-negative) mutant and one expressing a transdominant-

negative c-fms mutant (cfms TM) as a control. Beginning at the time when the first tumor appeared, tumor volumes were measured every 2 to 3 days to obtain growth curve. Each group is represented by four mice.

5

5. DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to the use of ligands for the FLK-1 receptor to modulate angiogenesis and/or vasculogenesis. The invention also involves the 10 expression of Flk-1 to evaluate and screen for drugs and analogs of VEGF that may be involved in receptor activation, regulation and uncoupling. Such regulators of Flk-1 may be used therapeutically. For example, 15 agonists of VEGF may be used in processes such as wound healing; in contrast, antagonists of VEGF may be used in the treatment of tumors that rely on vascularization for growth.

The invention, is based, in part, on results from *in situ*-hybridization and Northern blot analyses indicating 20 that Flk-1 is an endothelial cell specific RTK. In addition, cross-linking experiments have shown Flk-1 to be a high affinity receptor for vascular endothelial growth factor (VEGF), indicating that Flk-1 plays a crucial role in the development and differentiation of 25 hemangioblast and in subsequent endothelial cell growth during vasculogenesis and angiogenesis.

The invention is based, also, on the discovery that expression of a transdominant-negative mutant form of the Flk-1 molecule can inhibit the biological activity of the 30 endogenous wild type Flk-1. Experiments are described herein, in which tumor cells and cells producing a recombinant retrovirus encoding a truncated Flk-1 receptor were mixed and injected into mice. Inhibition of vasculogenesis and growth of the injected tumor cells 35 was observed in mice expressing the truncated form of the

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Flk-1 receptor. Expression of transdominant negative forms of the Flk-1 molecule may be useful for treatment of diseases resulting from abnormal proliferation of blood vessels, such as rheumatoid arthritis,

5 retinopathies and growth of solid tumors.

As explained in the working examples, *infra*, the polymerase chain reaction (PCR) method was used to isolate new receptor tyrosine kinases specifically expressed in post-implantation embryos and endothelial

10 cells. One such clone was found to encode a RTK that had almost identical sequence homology with the previously identified cDNA clone isolated from populations of cells enriched for hematopoietic cells and designated fetal liver kinase-1 (Flk-1) (Matthews et al., 1991, Proc.

15 Natl. Acad Sci. U.S.A. 88:9026-9030) (FIG. 11).

For clarity of discussion, the invention is described in the subsections below by way of example for the murine Flk-1. However, the principles may be analogously applied to clone and express the Flk-1 of

20 other species including humans.

5.1. THE Flk-1 CODING SEQUENCE

The nucleotide coding sequence and deduced amino acid sequence of the murine Flk-1 gene is depicted in

25 Figure 11 (SEQ. ID NO. 1) and has recently been described in Matthews et al., 1991, Proc. Natl. Acad. Sci. U.S.A., 88:9026-9030. In accordance with the invention, the nucleotide sequence of the Flk-1 protein or its functional equivalent in mammals, including humans, can 30 be used to generate recombinant molecules which direct the expression of Flk-1; hereinafter, this receptor will be referred to as "Flk-1", regardless of the species from which it is derived.

In a specific embodiment described herein, the 35 murine Flk-1 gene was isolated by performing a polymerase

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chain reaction (PCR) using two degenerate oligonucleotide primer pools that were designed on the basis of highly conserved sequences within the kinase domain of receptor tyrosine kinases (Hanks et al., 1988,.) As a template, 5 DNA from a λgt10 cDNA library prepared from day 8.5 mouse embryos, was used. In a parallel approach, similar primers were used to amplify RTK cDNA sequences from capillary endothelial cells that had been isolated from the brains of post-natal day 4-8 mice. This is a time 10 when brain endothelial cell proliferation is maximal. Both approaches yielded cDNA sequences encoding the recently described fetal liver RTK, Flk-1 (Matthews et al., 1991). Based on amino acid homology, this receptor is a member of the type III subclass of RTKs (Ullrich and 15 Schlessinger) which contain immunoglobulin-like repeats in their extracellular domains (FIG. 1).

The invention also relates to Flk-1 genes isolated from other species, including humans, in which Flk-1 activity exists. Members of the Flk-1 family are defined 20 herein as those receptors that bind VEGF or fragments of the peptide. Such receptors may demonstrate about 80% homology at the amino acid level in substantial stretches of DNA sequence. A bacteriophage cDNA library may be screened, under conditions of reduced stringency, using a 25 radioactively labeled fragment of the mouse Flk-1 clone. Alternatively the mouse Flk-1 sequence can be used to design degenerate or fully degenerate oligonucleotide probes which can be used as PCR probes or to screen bacteriophage cDNA libraries. A polymerase chain 30 reaction (PCR) based strategy may be used to clone human Flk-1. Two pools of degenerate oligonucleotides, corresponding to a conserved motifs between the mouse Flk-1 and receptor tyrosine kinases, may be designed to serve as primers in a PCR reaction. The template for the 35 reaction is cDNA obtained by reverse transcription of

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mRNA prepared from cell lines or tissue known to express human Flk-1. The PCR product may be subcloned and sequenced to insure that the amplified sequences represent the Flk-1 sequences. The PCR fragment may be

- 5 used to isolate a full length Flk-1 cDNA clone by radioactively labeling the amplified fragment and screening a bacteriophage cDNA library. Alternatively, the labeled fragment may be used to screen a genomic library. For a review of cloning strategies which may be
- 10 used, see e.g., Maniatis, 1989, Molecular Cloning, A Laboratory Manual, Cold Springs Harbor Press, N.Y.; and Ausubel et al., 1989, Current Protocols in Molecular Biology, (Green Publishing Associates and Wiley Interscience, N.Y.)

- 15 Isolation of a human Flk-1 cDNA may also be achieved by construction of a cDNA library in a mammalian expression vector such as pcDNA1, that contains SV40 origin of replication sequences which permit high copy number expression of plasmids when transferred into COS cells. The expression of Flk-1 on the surface of transfected COS cells may be detected in a number of ways, including the use of a labeled ligand such as VEGF or a VEGF agonist labeled with a radiolabel, fluorescent label or an enzyme. Cells expressing the human Flk-1 may
- 20 be enriched by subjecting transfected cells to a FACS (fluorescent activated cell sorter) sort.

In accordance with the invention, Flk-1 nucleotide sequences which encode Flk-1, peptide fragments of Flk-1, Flk-1 fusion proteins or functional equivalents thereof may be used to generate recombinant DNA molecules that direct the expression of Flk-1 protein or a functionally equivalent thereof, in appropriate host cells. Alternatively, nucleotide sequences which hybridize to portions of the Flk-1 sequence may also be used in

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nucleic acid hybridization assays, Southern and Northern blot analyses, etc.

Due to the inherent degeneracy of the genetic code, other DNA sequences which encode substantially the same 5 or a functionally equivalent amino acid sequence, may be used in the practice of the invention for the cloning and expression of the Flk-1 protein. Such DNA sequences include those which are capable of hybridizing to the murine Flk-1 sequence under stringent conditions.

10 Altered DNA sequences which may be used in accordance with the invention include deletions, additions or substitutions of different nucleotide residues resulting in a sequence that encodes the same or a functionally equivalent gene product. The gene product itself may 15 contain deletions, additions or substitutions of amino acid residues within the Flk-1 sequence, which result in a silent change thus producing a functionally equivalent Flk-1. Such amino acid substitutions may be made on the basis of similarity in polarity, charge, solubility, 20 hydrophobicity, hydrophilicity, and/or the amphipatic nature of the residues involved. For example, negatively charged amino acids include aspartic acid and glutamic acid; positively charged amino acids include lysine and arginine; amino acids with uncharged polar head groups 25 having similar hydrophilicity values include the following: leucine, isoleucine, valine; glycine, alanine; asparagine, glutamine; serine, threonine; phenylalanine, tyrosine. As used herein, a functionally equivalent Flk-1 refers to a receptor which binds to VEGF or fragments, 30 but not necessarily with the same binding affinity of its counterpart native Flk-1.

The DNA sequences of the invention may be engineered in order to alter the Flk-1 coding sequence for a variety of ends including but not limited to alterations which 35 modify processing and expression of the gene product.

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For example, mutations may be introduced using techniques which are well known in the art, e.g. site-directed mutagenesis, to insert new restriction sites, to alter glycosylation patterns, phosphorylation, etc. For

5 example, in certain expression systems such as yeast, host cells may over glycosylate the gene product. When using such expression systems it may be preferable to alter the Flk-1 coding sequence to eliminate any N-linked glycosylation site.

10 In another embodiment of the invention, the Flk-1 or a modified Flk-1 sequence may be ligated to a heterologous sequence to encode a fusion protein. For example, for screening of peptide libraries it may be useful to encode a chimeric Flk-1 protein expressing a 15 heterologous epitope that is recognized by a commercially available antibody. A fusion protein may also be engineered to contain a cleavage site located between the Flk-1 sequence and the heterologous protein sequence, so that the Flk-1 can be cleaved away from the heterologous 20 moiety.

In an alternate embodiment of the invention, the coding sequence of Flk-1 could be synthesized in whole or in part, using chemical methods well known in the art.

See, for example, Caruthers, et al., 1980, Nuc. Acids

25 Res. Symp. Ser. 7:215-233; Crea and Horn, 180, Nuc. Acids Res. 9(10):2331; Matteucci and Caruthers, 1980, Tetrahedron Letters 21:719; and Chow and Kempe, 1981, Nuc. Acids Res. 9(12):2807-2817. Alternatively, the protein itself could be produced using chemical methods 30 to synthesize the Flk-1 amino acid sequence in whole or in part. For example, peptides can be synthesized by solid phase techniques, cleaved from the resin, and purified by preparative high performance liquid chromatography. (E.g., see Creighton, 1983, Proteins 35 Structures And Molecular Principles, W.H. Freeman and

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Co., N.Y. pp. 50-60). The composition of the synthetic peptides may be confirmed by amino acid analysis or sequencing (e.g., the Edman degradation procedure; see Creighton, 1983, Proteins, Structures and Molecular 5 Principles, W.H. Freeman and Co., N.Y., pp. 34-49.

5.2. EXPRESSION OF Flk-1 RECEPTOR AND GENERATION OF CELL LINES THAT EXPRESS Flk-1

In order to express a biologically active Flk-1, the 10 nucleotide sequence coding for Flk-1, or a functional equivalent as described in Section 5.1 supra, is inserted into an appropriate expression vector, i.e., a vector which contains the necessary elements for the transcription and translation of the inserted coding 15 sequence. The Flk-1 gene products as well as host cells or cell lines transfected or transformed with recombinant Flk-1 expression vectors can be used for a variety of purposes. These include but are not limited to generating antibodies (i.e., monoclonal or polyclonal) 20 that bind to the receptor, including those that competitively inhibit binding of VEGF and "neutralize" activity of Flk-1 and the screening and selection of VEGF analogs or drugs that act via the Flk-1 receptor; etc.

25 5.2.1. EXPRESSION SYSTEMS

Methods which are well known to those skilled in the art can be used to construct expression vectors containing the Flk-1 coding sequence and appropriate transcriptional/translational control signals. These 30 methods include in vitro recombinant DNA techniques, synthetic techniques and in vivo recombination/genetic recombination. See, for example, the techniques described in Maniatis et al., 1989, Molecular Cloning A Laboratory Manual, Cold Spring Harbor Laboratory, N.Y. 35 and Ausubel et al., 1989, Current Protocols in Molecular

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Biology, Greene Publishing Associates and Wiley
Interscience, N.Y.

A variety of host-expression vector systems may be utilized to express the Flk-1 coding sequence. These 5 include but are not limited to microorganisms such as bacteria transformed with recombinant bacteriophage DNA, plasmid DNA or cosmid DNA expression vectors containing the Flk-1 coding sequence; yeast transformed with recombinant yeast expression vectors containing the Flk-1 10 coding sequence; insect cell systems infected with recombinant virus expression vectors (e.g., baculovirus) containing the Flk-1 coding sequence; plant cell systems infected with recombinant virus expression vectors (e.g., cauliflower mosaic virus, CaMV; tobacco mosaic virus; 15 TMV) or transformed with recombinant plasmid expression vectors (e.g., Ti plasmid) containing the Flk-1 coding sequence; or animal cell systems infected with recombinant virus expression vectors (e.g., adenovirus, vaccinia virus) including cell lines engineered to 20 contain multiple copies of the Flk-1 DNA either stably amplified (CHO/dhfr) or unstably amplified in double-minute chromosomes (e.g., murine cell lines).

The expression elements of these systems vary in their strength and specificities. Depending on the 25 host/vector system utilized, any of a number of suitable transcription and translation elements, including constitutive and inducible promoters, may be used in the expression vector. For example, when cloning in bacterial systems, inducible promoters such as pL of 30 bacteriophage λ , plac, ptrp, ptac (ptrp-lac hybrid promoter) and the like may be used; when cloning in insect cell systems, promoters such as the baculovirus polyhedrin promoter may be used; when cloning in plant cell systems, promoters derived from the genome of plant 35 cells (e.g., heat shock promoters; the promoter for the

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small subunit of RUBISCO; the promoter for the chlorophyll a/b binding protein) or from plant viruses (e.g., the 35S RNA promoter of CaMV; the coat protein promoter of TMV) may be used; when cloning in mammalian cell systems, promoters derived from the genome of mammalian cells (e.g., metallothionein promoter) or from mammalian viruses (e.g., the adenovirus late promoter; the vaccinia virus 7.5K promoter) may be used; when generating cell lines that contain multiple copies of the 10 Flk-1 DNA SV40-, BPV- and EBV-based vectors may be used with an appropriate selectable marker.

In bacterial systems a number of expression vectors may be advantageously selected depending upon the use intended for the Flk-1 expressed. For example, when 15 large quantities of Flk-1 are to be produced for the generation of antibodies or to screen peptide libraries, vectors which direct the expression of high levels of fusion protein products that are readily purified may be desirable. Such vectors include but are not limited to 20 the *E. coli* expression vector pUR278 (Ruther et al., 1983, EMBO J. 2:1791), in which the Flk-1 coding sequence may be ligated into the vector in frame with the lac Z coding region so that a hybrid AS-lac Z protein is produced; pIN vectors (Inouye & Inouye, 1985, Nucleic 25 acids Res. 13:3101-3109; Van Heeke & Schuster, 1989, J. Biol. Chem. 264:5503-5509); and the like. pGEX vectors may also be used to express foreign polypeptides as fusion proteins with glutathione S-transferase (GST). In general, such fusion proteins are soluble and can easily 30 be purified from lysed cells by adsorption to glutathione-agarose beads followed by elution in the presence of free glutathione. The pGEX vectors are designed to include thrombin or factor Xa protease cleavage sites so that the cloned polypeptide of interest 35 can be released from the GST moiety.

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In yeast, a number of vectors containing constitutive or inducible promoters may be used. For a review see, *Current Protocols in Molecular Biology*, Vol. 2, 1988, Ed. Ausubel et al., Greene Publish. Assoc. & Wiley Interscience, Ch. 13; Grant et al., 1987, *Expression and Secretion Vectors for Yeast*, in *Methods in Enzymology*, Eds. Wu & Grossman, 1987, Acad. Press, N.Y., Vol. 153, pp. 516-544; Glover, 1986, *DNA Cloning*, Vol. II, IRL Press, Wash., D.C., Ch. 3; and Bitter, 1987, *Heterologous Gene Expression in Yeast*, *Methods in Enzymology*, Eds. Berger & Kimmel, Acad. Press, N.Y., Vol. 152, pp. 673-684; and *The Molecular Biology of the Yeast Saccharomyces*, 1982, Eds. Strathern et al., Cold Spring Harbor Press, Vols. I and II.

In cases where plant expression vectors are used, the expression of the Flk-1 coding sequence may be driven by any of a number of promoters. For example, viral promoters such as the 35S RNA and 19S RNA promoters of CaMV (Brisson et al., 1984, *Nature* 310:511-514), or the coat protein promoter of TMV (Takamatsu et al., 1987, *EMBO J.* 6:307-311) may be used; alternatively, plant promoters such as the small subunit of RUBISCO (Coruzzi et al., 1984, *EMBO J.* 3:1671-1680; Broglie et al., 1984, *Science* 224:838-843); or heat shock promoters, e.g., soybean hsp17.5-E or hsp17.3-B (Gurley et al., 1986, *Mol. Cell. Biol.* 6:559-565) may be used. These constructs can be introduced into plant cells using Ti plasmids, Ri plasmids, plant virus vectors, direct DNA transformation, microinjection, electroporation, etc. For reviews of such techniques see, for example, Weissbach & Weissbach, 1988, *Methods for Plant Molecular Biology*, Academic Press, NY, Section VIII, pp. 421-463; and Grierson & Corey, 1988, *Plant Molecular Biology*, 2d Ed., Blackie, London, Ch. 7-9.

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An alternative expression system which could be used to express Flk-1 is an insect system. In one such system, Autographa californica nuclear polyhedrosis virus (AcNPV) is used as a vector to express foreign genes.

5 The virus grows in Spodoptera frugiperda cells. The Flk-1 coding sequence may be cloned into non-essential regions (for example the polyhedrin gene) of the virus and placed under control of an AcNPV promoter (for example the polyhedrin promoter). Successful insertion 10 of the Flk-1 coding sequence will result in inactivation of the polyhedrin gene and production of non-occluded recombinant virus (i.e., virus lacking the proteinaceous coat coded for by the polyhedrin gene). These recombinant viruses are then used to infect Spodoptera 15 frugiperda cells in which the inserted gene is expressed. (E.g., see Smith et al., 1983, J. Virol. 46:584; Smith, U.S. Patent No. 4,215,051).

In mammalian host cells, a number of viral based expression systems may be utilized. In cases where an 20 adenovirus is used as an expression vector, the Flk-1 coding sequence may be ligated to an adenovirus transcription/translation control complex, e.g., the late promoter and tripartite leader sequence. This chimeric gene may then be inserted in the adenovirus genome by in 25 vitro or in vivo recombination. Insertion in a non-essential region of the viral genome (e.g., region E1 or E3) will result in a recombinant virus that is viable and capable of expressing Flk-1 in infected hosts. (E.g., See Logan & Shenk, 1984, Proc. Natl. Acad. Sci. (USA) 81:3655-3659). Alternatively, the vaccinia 7.5K promoter 30 may be used. (See, e.g., Mackett et al., 1982, Proc. Natl. Acad. Sci. (USA) 79:7415-7419; Mackett et al., 1984, J. Virol. 49:857-864; Panicali et al., 1982, Proc. Natl. Acad. Sci. 79:4927-4931).

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Specific initiation signals may also be required for efficient translation of inserted Flk-1 coding sequences. These signals include the ATG initiation codon and adjacent sequences. In cases where the entire Flk-1 5 gene, including its own initiation codon and adjacent sequences, is inserted into the appropriate expression vector, no additional translational control signals may be needed. However, in cases where only a portion of the Flk-1 coding sequence is inserted, exogenous 10 translational control signals, including the ATG initiation codon, must be provided. Furthermore, the initiation codon must be in phase with the reading frame of the Flk-1 coding sequence to ensure translation of the entire insert. These exogenous translational control 15 signals and initiation codons can be of a variety of origins, both natural and synthetic. The efficiency of expression may be enhanced by the inclusion of appropriate transcription enhancer elements, transcription terminators, etc. (see Bittner et al., 20 1987, Methods in Enzymol. 153:516-544).

In addition, a host cell strain may be chosen which modulates the expression of the inserted sequences, or modifies and processes the gene product in the specific fashion desired. Such modifications (e.g., 25 glycosylation) and processing (e.g., cleavage) of protein products may be important for the function of the protein. Different host cells have characteristic and specific mechanisms for the post-translational processing and modification of proteins. Appropriate cells lines or 30 host systems can be chosen to ensure the correct modification and processing of the foreign protein expressed. To this end, eukaryotic host cells which possess the cellular machinery for proper processing of the primary transcript, glycosylation, and 35 phosphorylation of the gene product may be used. Such

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mammalian host cells include but are not limited to CHO, VERO, BHK, HeLa, COS, MDCK, 293, WI38, etc.

For long-term, high-yield production of recombinant proteins, stable expression is preferred. For example,

- 5 cell lines which stably express the Flk-1 may be engineered. Rather than using expression vectors which contain viral origins of replication, host cells can be transformed with the Flk-1 DNA controlled by appropriate expression control elements (e.g., promoter, enhancer, sequences, transcription terminators, polyadenylation sites, etc.), and a selectable marker. Following the introduction of foreign DNA, engineered cells may be allowed to grow for 1-2 days in an enriched media, and then are switched to a selective media. The selectable marker in the recombinant plasmid confers resistance to the selection and allows cells to stably integrate the plasmid into their chromosomes and grow to form foci which in turn can be cloned and expanded into cell lines. This method may advantageously be used to engineer cell
- 10 lines which express the Flk-1 on the cell surface, and which respond to VEGF mediated signal transduction. Such engineered cell lines are particularly useful in screening VEGF analogs.
- 15
- 20
- 25

A number of selection systems may be used, including but not limited to the herpes simplex virus thymidine kinase (Wigler, et al., 1977, Cell 11:223), hypoxanthine-guanine phosphoribosyltransferase (Szybalska & Szybalski, 1962, Proc. Natl. Acad. Sci. USA 48:2026), and adenine phosphoribosyltransferase (Lowy, et al., 1980, Cell 22:817) genes can be employed in tk, hprt or aprt cells, respectively. Also, antimetabolite resistance can be used as the basis of selection for dhfr, which confers resistance to methotrexate (Wigler, et al., 1980, Natl. Acad. Sci. USA 77:3567; O'Hare, et al., 1981, Proc. Natl. Acad. Sci. USA 78:1527); gpt, which confers resistance to- 30
- 35

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mycophenolic acid (Mulligan & Berg, 1981), Proc. Natl. Acad. Sci. USA 78:2072); neo, which confers resistance to the aminoglycoside G-418 (Colberre-Garapin, et al., 1981, J. Mol. Biol. 150:1); and hygro, which confers resistance 5 to hygromycin (Santerre, et al., 1984, Gene 30:147) genes. Recently, additional selectable genes have been described, namely trpB, which allows cells to utilize indole in place of tryptophan; hisD, which allows cells to utilize histinol in place of histidine (Hartman & 10 Mulligan, 1988, Proc. Natl. Acad. Sci. USA 85:8047); and ODC (ornithine decarboxylase) which confers resistance to the ornithine decarboxylase inhibitor, 2-(difluoromethyl)-DL-ornithine, DFMO (McConlogue L., 1987, In: Current Communications in Molecular Biology, Cold 15 Spring Harbor Laboratory ed.).

5.2.2. IDENTIFICATION OF TRANSFECTANTS OR
TRANSFORMANTS THAT EXPRESS THE Flk-1

The host cells which contain the coding sequence and 20 which express the biologically active gene product may be identified by at least four general approaches; (a) DNA-DNA or DNA-RNA hybridization; (b) the presence or absence of "marker" gene functions; (c) assessing the level of transcription as measured by the expression of Flk-1 mRNA 25 transcripts in the host cell; and (d) detection of the gene product as measured by immunoassay or by its biological activity.

In the first approach, the presence of the Flk-1 coding sequence inserted in the expression vector can be 30 detected by DNA-DNA or DNA-RNA hybridization using probes comprising nucleotide sequences that are homologous to the Flk-1 coding sequence, respectively, or portions or derivatives thereof.

In the second approach, the recombinant expression 35 vector/host system can be identified and selected based

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upon the presence or absence of certain "marker" gene functions (e.g., thymidine kinase activity, resistance to antibiotics, resistance to methotrexate, transformation phenotype, occlusion body formation in baculovirus,

5 etc.). For example, if the Flk-1 coding sequence is inserted within a marker gene sequence of the vector, recombinants containing the Flk-1 coding sequence can be identified by the absence of the marker gene function. Alternatively, a marker gene can be placed in tandem with
10 the Flk-1 sequence under the control of the same or different promoter used to control the expression of the Flk-1 coding sequence. Expression of the marker in response to induction or selection indicates expression of the Flk-1 coding sequence.

15 In the third approach, transcriptional activity for the Flk-1 coding region can be assessed by hybridization assays. For example, RNA can be isolated and analyzed by Northern blot using a probe homologous to the Flk-1 coding sequence or particular portions thereof.

20 Alternatively, total nucleic acids of the host cell may be extracted and assayed for hybridization to such probes.

In the fourth approach, the expression of the Flk-1 protein product can be assessed immunologically, for
25 example by Western blots, immunoassays such as radioimmuno-precipitation, enzyme-linked immunoassays and the like. The ultimate test of the success of the expression system, however, involves the detection of the biologically active Flk-1 gene product. A number of
30 assays can be used to detect receptor activity including but not limited to VEGF binding assays; and VEGF biological assays using engineered cell lines as the test substrate.

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5.3. USES OF THE Flk-1 RECEPTOR
AND ENGINEERED CELL LINES

Angiogenesis, the growth of new blood capillary vessels, is required for a number of physiological processes ranging from wound healing, tissue and organ regeneration, placental formation after pregnancy and embryonic development. Abnormal proliferation of blood vessels is an important component of a variety of diseases such as rheumatoid arthritis, retinopathies, and psoriasis. Angiogenesis is also an important factor in the growth and metastatic activity of solid tumors that rely on vascularization. Therefore, inhibitors of angiogenesis may be used therapeutically for the treatment of diseases resulting from or accompanied by abnormal growth of blood vessels and for treatments of malignancies involving growth and spread of solid tumors.

In an embodiment of the invention the Flk-1 receptor and/or cell lines that express the Flk-1 receptor may be used to screen for antibodies, peptides, or other ligands that act as agonists or antagonists of angiogenesis or vasculogenesis mediated by the Flk-1 receptor. For example, anti-Flk-1 antibodies capable of neutralizing the activity of VEGF, may be used to inhibit Flk-1 function. Additionally, anti-Flk-1 antibodies which mimic VEGF activity may be selected for uses in wound healing. Alternatively, screening of peptide libraries with recombinantly expressed soluble Flk-1 protein or cell lines expressing Flk-1 protein may be useful for identification of therapeutic molecules that function by inhibiting the biological activity of Flk-1.

In an embodiment of the invention, engineered cell lines which express the entire Flk-1 coding region or its ligand binding domain may be utilized to screen and identify VEGF antagonists as well as agonists. Synthetic compounds, natural products, and other sources of

potentially biologically active materials can be screened in a number of ways. The ability of a test compound to inhibit binding of VEGF to Flk-1 may be measured using standard receptor binding techniques, such as those 5 described in Section 6.1.9. The ability of agents to prevent or mimic, the effect of VEGF binding on signal transduction responses on Flk-1 expressing cells may be measured. For example, responses such as activation of Flk-1 kinase activity, modulation of second messenger 10 production or changes in cellular metabolism may be monitored. These assays may be performed using conventional techniques developed for these purposes.

5.3.1. SCREENING OF PEPTIDE LIBRARY WITH
Flk-1 PROTEIN OR ENGINEERED CELL LINES

15 Random peptide libraries consisting of all possible combinations of amino acids attached to a solid phase support may be used to identify peptides that are able to bind to the ligand binding site of a given receptor or 20 other functional domains of a receptor such as kinase domains (Lam, K.S. et al., 1991, Nature 354: 82-84). The screening of peptide libraries may have therapeutic value in the discovery of pharmaceutical agents that act to inhibit the biological activity of receptors through 25 their interactions with the given receptor.

Identification of molecules that are able to bind to the Flk-1 may be accomplished by screening a peptide library with recombinant soluble Flk-1 protein. Methods for expression and purification of Flk-1 are described in 30 Section 5.2.1 and may be used to express recombinant full length Flk-1 or fragments of Flk-1 depending on the functional domains of interest. For example, the kinase and extracellular ligand binding domains of Flk-1 may be separately expressed and used to screen peptide 35 libraries.

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To identify and isolate the peptide/solid phase support that interacts and forms a complex with Flk-1, it is necessary to label or "tag" the Flk-1 molecule. The Flk-1 protein may be conjugated to enzymes such as 5 alkaline phosphatase or horseradish peroxidase or to other reagents such as fluorescent labels which may include fluorescein isothiocyanate (FITC), phycoerythrin (PE) or rhodamine. Conjugation of any given label, to Flk-1, may be performed using techniques that are routine 10 in the art. Alternatively, Flk-1 expression vectors may be engineered to express a chimeric Flk-1 protein containing an epitope for which a commercially available antibody exist. The epitope specific antibody may be tagged using methods well known in the art including 15 labeling with enzymes, fluorescent dyes or colored or magnetic beads.

The "tagged" Flk-1 conjugate is incubated with the random peptide library for 30 minutes to one hour at 22°C to allow complex formation between Flk-1 and peptide 20 species within the library. The library is then washed to remove any unbound Flk-1 protein. If Flk-1 has been conjugated to alkaline phosphatase or horseradish peroxidase the whole library is poured into a petri dish containing a substrates for either alkaline phosphatase 25 or peroxidase, for example, 5-bromo-4-chloro-3-indoyl phosphate (BCIP) or 3,3',4,4"-diaminobenzidine (DAB), respectively. After incubating for several minutes, the peptide/solid phase-Flk-1 complex changes color, and can be easily identified and isolated physically under a 30 dissecting microscope with a micromanipulator. If a fluorescent tagged Flk-1 molecule has been used, complexes may be isolated by fluorescent activated sorting. If a chimeric Flk-1 protein expressing a heterologous epitope has been used, detection of the 35 peptide/Flk-1 complex may be accomplished by using a

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labeled epitope specific antibody. Once isolated, the identity of the peptide attached to the solid phase support may be determined by peptide sequencing.

In addition to using soluble Flk-1 molecules, in 5 another embodiment, it is possible to detect peptides that bind to cell surface receptors using intact cells. The use of intact cells is preferred for use with receptors that are multi-subunits or labile or with receptors that require the lipid domain of the cell 10 membrane to be functional. Methods for generating cell lines expressing Flk-1 are described in Sections 5.2.1. and 5.2.2. The cells used in this technique may be either live or fixed cells. The cells will be incubated with the random peptide library and will bind to certain 15 peptides in the library to form a "rosette" between the target cells and the relevant solid phase support/peptide. The rosette can thereafter be isolated by differential centrifugation or removed physically under a dissecting microscope.

20 As an alternative to whole cell assays for membrane bound receptors or receptors that require the lipid domain of the cell membrane to be functional, the receptor molecules can be reconstituted into liposomes where label or "tag" can be attached.

25

5.3.2. ANTIBODY PRODUCTION AND SCREENING

Various procedures known in the art may be used for the production of antibodies to epitopes of the 30 recombinantly produced Flk-1 receptor. Such antibodies include but are not limited to polyclonal, monoclonal, chimeric, single chain, Fab fragments and fragments produced by an Fab expression library. Neutralizing antibodies i.e., those which compete for the VEGF binding 35

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site of the receptor are especially preferred for diagnostics and therapeutics.

Monoclonal antibodies that bind Flk-1 may be radioactively labeled allowing one to follow their

5 location and distribution in the body after injection. Radioactivity tagged antibodies may be used as a non-invasive diagnostic tool for imaging *de novo* vascularization associated with a number of diseases including rheumatoid arthritis, macular degeneration, and

10 formation of tumors and metastases.

Immunotoxins may also be designed which target cytotoxic agents to specific sites in the body. For example, high affinity Flk-1 specific monoclonal antibodies may be covalently complexed to bacterial or

15 plant toxins, such as diphtheria toxin, abrin or ricin. A general method of preparation of antibody/hybrid molecules may involve use of thiol-crosslinking reagents such as SPDP, which attack the primary amino groups on the antibody and by disulfide exchange, attach the toxin

20 to the antibody. The hybrid antibodies may be used to specifically eliminate Flk-1 expressing endothelial cells.

For the production of antibodies, various host animals may be immunized by injection with the Flk-1

25 protein including but not limited to rabbits, mice, rats, etc. Various adjuvants may be used to increase the immunological response, depending on the host species, including but not limited to Freund's (complete and incomplete), mineral gels such as aluminum hydroxide, 30 surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil emulsions, keyhole limpet hemocyanin, dinitrophenol, and potentially useful human adjuvants such as BCG (bacille Calmette-Guerin) and

Corynebacterium parvum.

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Monoclonal antibodies to Flk-1 may be prepared by using any technique which provides for the production of antibody molecules by continuous cell lines in culture.

These include but are not limited to the hybridoma

5 technique originally described by Kohler and Milstein, (Nature, 1975, 256:495-497), the human B-cell hybridoma technique (Kosbor et al., 1983, Immunology Today, 4:72; Cote et al., 1983, Proc. Natl. Acad. Sci., 80:2026-2030) and the EBV-hybridoma technique (Cole et al., 1985,

10 Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, Inc., pp. 77-96). In addition, techniques developed for the production of "chimeric antibodies" (Morrison et al., 1984, Proc. Natl. Acad. Sci., 81:6851-6855; Neuberger et al., 1984, Nature, 312:604-608; Takeda et al., 1985,

15 Nature, 314:452-454) by splicing the genes from a mouse antibody molecule of appropriate antigen specificity together with genes from a human antibody molecule of appropriate biological activity can be used.

Alternatively, techniques described for the production of

20 single chain antibodies (U.S. Patent 4,946,778) can be adapted to produce Flk-1-specific single chain antibodies.

Antibody fragments which contain specific binding sites of Flk-1 may be generated by known techniques. For 25 example, such fragments include but are not limited to: the F(ab'), fragments which can be produced by pepsin digestion of the antibody molecule and the Fab fragments which can be generated by reducing the disulfide bridges of the F(ab'), fragments. Alternatively, Fab expression 30 libraries may be constructed (Huse et al., 1989, Science, 246:1275-1281) to allow rapid and easy identification of monoclonal Fab fragments with the desired specificity to Flk-1.

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The Flk-1 coding sequence may be used for diagnostic purposes for detection of Flk-1 expression. Included in the scope of the invention are oligoribonucleotide sequences, that include antisense RNA and DNA molecules and ribozymes that function to inhibit translation of Flk-1. In addition, mutated forms of Flk-1, having a dominant negative effect, may be expressed in targeted cell populations to inhibit the activity of endogenously expressed wild-type Flk-1.

10

5.4.1. USE OF Flk-1 CODING SEQUENCE
IN DIAGNOSTICS AND THERAPEUTICS

The Flk-1 DNA may have a number of uses for the diagnosis of diseases resulting from aberrant expression 15 of Flk-1. For example, the Flk-1 DNA sequence may be used in hybridization assays of biopsies or autopsies to diagnose abnormalities of Flk-1 expression; e.g., Southern or Northern analysis, including in situ hybridization assays.

20 The Flk-1 cDNA may be used as a probe to detect the expression of the Flk-1 mRNA. In a specific example described herein, the expression of Flk-1 mRNA in mouse embryos of different developmental stages was analyzed. Northern blot analysis indicated abundant expression of a 25 major 5.5 kb mRNA between day 9.5 and day 18.5, with apparent decline towards the end of gestation (FIG. 2A). In post-natal day 4-8 brain capillaries Flk-1 mRNA was found to be highly enriched compared to total brain RNA (FIG. 2B), suggesting a role for Flk-1 in endothelial cell 30 proliferation.

To obtain more detailed information about the expression of Flk-1 during embryonic development and during the early stages of vascular development in situ hybridization experiments were performed as described in 35 Section 6.1.4. In situ hybridizations demonstrated that

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Flk-1 expression in vivo during embryonic mouse development is largely restricted to endothelial cells and their precursors (FIG. 3 and FIG. 4). Flk-1 is expressed in endothelial cells during physiological processes that are characterized by endothelial cell proliferation and the temporal and spatial expression pattern found in the embryonic brain correlate precisely with the development of the neural vascular system as described by Bar (1980). Vascular sprouts originating in the perineural plexus grow radially into the neuroectoderm and branch there and these sprouts were found to express high amounts of Flk-1 mRNA (FIG. 5). In the early postnatal stages endothelial cell proliferation is still evident and Flk-1 is expressed, whereas in the adult organism, after completion of the vascularization process, the decline in endothelial cell proliferation parallels a decrease in Flk-1 expression.

Also within the scope of the invention are oligoribonucleotide sequences, that include anti-sense RNA and DNA molecules and ribozymes that function to inhibit the translation of Flk-1 mRNA. Anti-sense RNA and DNA molecules act to directly block the translation of mRNA by binding to targeted mRNA and preventing protein translation. In regard to antisense DNA, oligodeoxyribonucleotides derived from the translation initiation site, e.g., between -10 and +10 regions of the Flk-1 nucleotide sequence, are preferred.

Ribozymes are enzymatic RNA molecules capable of catalyzing the specific cleavage of RNA. The mechanism of ribozyme action involves sequence specific hybridization of the ribozyme molecule to complementary target RNA, followed by a endonucleolytic cleavage. Within the scope of the invention are engineered hammerhead motif ribozyme molecules that specifically and

efficiently catalyze endonucleolytic cleavage of Flk-1 RNA sequences.

Specific ribozyme cleavage sites within any potential RNA target are initially identified by scanning 5 the target molecule for ribozyme cleavage sites which include the following sequences, GUA, GUU and GUC. Once identified, short RNA sequences of between 15 and 20 ribonucleotides corresponding to the region of the target gene containing the cleavage site may be evaluated for 10 predicted structural features such as secondary structure that may render the oligonucleotide sequence unsuitable. The suitability of candidate targets may also be evaluated by testing their accessibility to hybridization with complementary oligonucleotides, using ribonuclease 15 protection assays.

Both anti-sense RNA and DNA molecules and ribozymes of the invention may be prepared by any method known in the art for the synthesis of RNA molecules. These include techniques for chemically synthesizing 20 oligodeoxyribonucleotides well known in the art such as for example solid phase phosphoramidite chemical synthesis. Alternatively, RNA molecules may be generated by *in vitro* and *in vivo* transcription of DNA sequences encoding the antisense RNA molecule. Such DNA sequences 25 may be incorporated into a wide variety of vectors which incorporate suitable RNA polymerase promoters such as the T7 or SP6 polymerase promoters. Alternatively, antisense cDNA constructs that synthesize antisense RNA constitutively or inducibly, depending on the promoter 30 used, can be introduced stably into cell lines.

Various modifications to the DNA molecules may be introduced as a means of increasing intracellular stability and half-life. Possible modifications include but are not limited to the addition of flanking sequences 35 of ribo- or deoxy- nucleotides to the 5' and/or 3' ends

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of the molecule or the use of phosphorothioate or 2' O-methyl rather than phosphodiesterase linkages within the oligodeoxyribonucleotide backbone.

5 5.4.2. USE OF DOMINANT NEGATIVE
Flk-1 MUTANTS IN GENE THERAPY

Receptor dimerization induced by ligands, is thought to provide an allosteric regulatory signal that functions to couple ligand binding to stimulation of kinase 10 activity. Defective receptors can function as dominant negative mutations by suppressing the activation and response of normal receptors by formation of unproductive heterodimers. Therefore, defective receptors can be engineered into recombinant viral vectors and used in 15 gene therapy in individuals that inappropriately express Flk-1.

In an embodiment of the invention, mutant forms of the Flk-1 molecule having a dominant negative effect may be identified by expression in selected cells. Deletion 20 or missense mutants of Flk-1 that retain the ability to form dimers with wild type Flk-1 protein but cannot function in signal transduction may be used to inhibit the biological activity of the endogenous wild type Flk-1. For example, the cytoplasmic kinase domain of Flk-1 25 may be deleted resulting in a truncated Flk-1 molecule that is still able to undergo dimerization with endogenous wild type receptors but unable to transduce a signal.

Abnormal proliferation of blood vessels is an 30 important component of a variety of pathogenic disorders such as rheumatoid arthritis, retinopathies and psoriasis. Uncontrolled angiogenesis is also an important factor in the growth and metastases of solid tumors. Recombinant viruses may be engineered to express 35 dominant negative forms of Flk-1 which may be used to

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inhibit the activity of the wild type endogenous Flk-1. These viruses may be used therapeutically for treatment of diseases resulting from aberrant expression or activity of Flk-1.

5 Expression vectors derived from viruses such as retroviruses, vaccinia virus, adeno-associated virus, herpes viruses, or bovine papilloma virus, may be used for delivery of recombinant Flk-1 into the targeted cell population. Methods which are well known to those skilled in the art can be used to construct recombinant viral vectors containing Flk-1 coding sequence. See, for example, the techniques described in Maniatis et al., 10 1989, Molecular Cloning A Laboratory Manual, Cold Spring Harbor Laboratory, N.Y. and Ausubel et al., 1989, Current 15 Protocols in Molecular Biology, Greene Publishing Associates and Wiley Interscience, N.Y. Alternatively, recombinant Flk-1 molecules can be reconstituted into liposomes for delivery to target cells.

In a specific embodiment of the invention, a 20 deletion mutant of the Flk-1 receptor was engineered into a recombinant retroviral vector. Two clonal isolates designated pLXSN Flk-1 TM cl.1 and pLXSN Flk-1 TM cl.3 contain a truncated Flk-1 receptor lacking the 561 COOH-terminal amino acids. To obtain virus producing cell 25 lines, PA37 cells were transfected with the recombinant vectors and, subsequently, conditioned media containing virus were used to infect GPE cells.

To test whether expression of signaling-defective mutants inhibits endogenous Flk-1 receptor activity, C6 30 rat glioblastoma cells (tumor cells) and mouse cells producing the recombinant retroviruses were mixed and injected subcutaneously into nude mice. Normally, injection of tumor cells into nude mice would result in proliferation of the tumor cells and vascularization of 35 the resulting tumor mass. Since Flk-1 is believed to be

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essential for formation of blood vessels, blocking Flk-1 activity by expression of a truncated receptor, might function to inhibit vascularization of the developing tumor and, thereby, inhibit its growth. As illustrated 5 in Figures 13 and 14, coinjection of virus producing cells, expressing a truncated Flk-1 receptor, significantly inhibits the growth of the tumor as compared to controls receiving only tumor cells.

10 5.5. USE OF Flk-1 RECEPTOR OR LIGANDS

Receptor/ligand interaction between Flk-1 and VEGF is believed to play an important role in the signalling system during vascularization and angiogenesis. Abnormal proliferation of blood vessels is an important component 15 of a number of diseases.

Expression of Flk-1 RNA correlates with the development of the brain and with endothelial cell proliferation suggesting that Flk-1 might be a receptor involved in mediation of signaling events in the 20 vascularization process. VEGF has been shown to be a mitogenic growth factor known to act exclusively on endothelial cell (Ferrara, N. and Henzel, W.J., 1989, Biochem. Biophys. Res. Comm. 161:851-858). Cross-linking and ligand binding experiments were performed, as 25 described in Section 6.1.9 and 6.1.10 respectively, to determine whether VEGF is a ligand for Flk-1 and the results indicate that Flk-1 is an authentic high affinity VEGF receptor (FIG 9).

In one embodiment of the invention, ligands for 30 Flk-1, the Flk-1 receptor itself, or a fragment containing its VEGF binding site, could be administered in vivo to modulate angiogenesis and/or vasculogenesis. For example, administration of the Flk-1 receptor or a fragment containing the VEGF binding site, could 35 competitively bind to VEGF and inhibit its interaction

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with the native Flk-1 receptor in vivo to inhibit angiogenesis and/or vasculogenesis. Alternatively, ligands for Flk-1, including anti-Flk-1 antibodies or fragments thereof, may be used to modulate angiogenesis 5 and/or vasculogenesis. Agonists of VEGF activity may be used to promote wound healing whereas antagonists of VEGF activity may be used to inhibit tumor growth.

Depending on the specific conditions being treated, these agents may be formulated and administered 10 systemically or locally. Techniques for formulation and administration may be found in "Remington's Pharmaceutical Sciences," Mack Publishing Co., Easton, PA, latest edition. Suitable routes may include oral, rectal, transmucosal, or intestinal administration; 15 parenteral delivery, including intramuscular, subcutaneous, intramedullary injections, as well as intrathecal, direct intraventricular, intravenous, intraperitoneal, intranasal, or intraocular injections, just to name a few. For injection, the agents of the 20 invention may be formulated in aqueous solutions, preferably in physiologically compatible buffers such as Hanks's solution, Ringer's solution, or physiological saline buffer. For such transmucosal administration, penetrants appropriate to the barrier to be permeated are 25 used in the formulation. Such penetrants are generally known in the art.

6. EXAMPLE: CLONING AND EXPRESSION PATTERNS
OF FLK-1, A HIGH AFFINITY
RECEPTOR FOR VEGF

30 The subsection below describes the cloning and characterization of the Flk-1 cDNA clone. Northern blot and *in situ* hybridization analyses indicate that Flk-1 is expressed in endothelial cells. Cross-linking and ligand binding experiments further indicate that Flk-1 is a high 35 affinity receptor for VEGF.

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6.1. MATERIALS AND METHODS

6.1.1. CDNA CLONING OF Flk-1

DNA extracted from λgt10 cDNA library of day 8.5
5 mouse embryos (Fahrner et al., 1987, EMBO. J. 6:1497-
1508) was used as template for polymerase chain reaction
(PCR; Saiki, R.K. et al., 1985 Science 230:1350-1354).
In an independent approach cDNA of capillary endothelial
cells that had been isolated from the brain of postnatal
10 day 4-8 mice was used for amplification (Risau, W., 1990
In: development of the Vascular System. Issues Biomed.
Basel Karger 58-68 and Schnürch et al., unpublished)
Degenerated primers were designed on the basis of high
amino acid homologies within the kinase domain shared by
15 all RTKs (Wilks, A.F., 1989, Proc. Natl. Acad. Sci.
U.S.A. 86:1603-1607).

Full length cDNA clones of Flk-1 were isolated from
another day 8.5 mouse embryo cDNA library, which had been
prepared according to the method of Okayama and Berg
20 (1983), and a day 11.5 mouse embryo λgt11 library
(Clonetech) using the ³²P-labeled (Feinberg, A.P. and
Vogelstein, B. 1983 Anal. Biochem. 132:6-13) 210-bp PCR
fragment.

25 6.1.2. MOUSE EMBRYOS

Balb/c mice were mated overnight and the morning of
vaginal plug detection was defined as 1/2 day of
gestation. For Northern blot analysis the frozen embryos
were homogenized in 5 M guanidinium thiocyanate and RNA
30 was isolated as described (Ullrich, A. et al., 1985,
Nature 313:756-761). For in situ hybridization, the
embryos were embedded in Tissue-Tek (Miles), frozen on
the surface of liquid nitrogen and stored at -70C prior
to use.

6.1.3. PREPARATION OF PROBES

The 5'-located 2619 bp of the receptor cDNA were subcloned in the pGem3Z vector (Promega) as an EcoR1/BamH1 fragment. The probe for Northern blot hybridization was prepared by labelling the cDNA fragment with α -³²PdATP (Amersham) by random hexanucleotide priming (Boehringer; Feinberg, A.P. and Vogelstein, B., 1983 Anal. Biochem. 132:6-13).

For *in situ* hybridization a single-strand antisense DNA probe was prepared as described by Schnürch and Risau (Development, 1991 111:1143-54). The plasmid was linearized at the 3' end of the cDNA and a sense transcript was synthesized using SP6 RNA polymerase (Boehringer). The DNA was degraded using DNase (RNase) (Boehringer Mannheim). With the transcript, a random-primed cDNA synthesis with a α -³⁵S dATP (Amersham) was performed by reverse transcription with MMLV reverse transcriptase (BRL). To obtain small cDNA fragments of about 100 bp in average suitable for *in situ* hybridization, a high excess of primer was used. Subsequently the RNA transcript was partially hydrolyzed in 100 mM NaOH for 20 minutes at 70°C, and the probe was neutralized with the same amount of HCl and purified with a Sephadex C50 column. After ethanol precipitation the probe was dissolved at a final specific activity of 5×10^5 cpm. For control hybridization a sense probe was prepared with the same method.

6.1.4. RNA EXTRACTION AND NORTHERN ANALYSIS

Total cytoplasmic RNA was isolated according to the acidic phenol-method of Chromczynski and Sacchi (1987). Poly(A⁺) RNA aliquots were electrophoresed in 1.2% agarose formaldehyde (Sambrook, J. et al., 1989 Molecular Cloning: A Laboratory Manual 2nd ed. Cold Spring Harbor Laboratory Press) gels and transferred to nitrocellulose

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membranes (Schleicher & Schuell). Hybridizations were performed overnight in 50% formamide, 5 x SSC (750mM sodium chloride, 75mM sodium citrate), 5 x Denhardt's (0.1% Ficoll 400, 0.1% polyvinylpyrrolidone, 0.1% BSA) 5 and -0.5% SDS at 42°C with $1-3 \times 10^6$ cpm-ml⁻¹ of ³²P-Random primed DNA probe, followed by high stringency washes in 0.2 x SSC, 0.5% SDS at 52°C. The filters were exposed for 4 to 8 days.

10 6.1.5. IN SITU HYBRIDIZATION

Subcloning postfixation and hybridization was essentially performed according to Hogan et al. (1986). 10 µm thick sections were cut at -18°C on a Leitz cryostat. For prehybridization treatment no incubation 15 with 0.2M HCl for removing the basic proteins was performed. Sections were incubated with the ³⁵S-cDNA probe (5×10^4 cpm/µl) at 52°C in a buffer containing 50% formamide, 300 mM NaCl, 10 mM Tris-HCl, 10 mM NaPO₄ (pH 6.8), 5 mM EDTA, 0.02% Ficoll 400, 0.01% 20 polyvinylpyrrolidone 0.02% BSA 10 m /ml yeast RNA, 10% dextran sulfate, and 10 mM NaCl, 10 mM Tris-HCl, 10 mM NaPO₄ (pH 6.8), 5 mM EDTA, 10 Mm DTT at 52°C). For autoradiography, slides were coated with Kodak NTB2 film emulsion and exposed for eight days. After developing, 25 the sections were counterstained and toluidine blue or May-Grinwald.

6.1.6. PREPARATION OF ANTISERA

The 3' primed EcoRV/HindII fragment comprising the 30 128 C-terminal amino acids of Flk-1 was subcloned in the fusion protein expression vector pGEX3X (Smith, D.B. and Johnson, K.S., 1990 Gene. 67:31-40; Pharmacia). The fusion protein was purified as described and used for immunizing rabbits. After the second boost the rabbits

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were bled and the antiserum was used for immunoprecipitation.

6.1.7. TRANSIENT EXPRESSION
OF Flk-1 IN COS-1 CELLS

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Transfection of COS-1 cells was performed essentially as described by Chen and Okayama (1987 Mol. Cell. Biol. 7:2745-2752) and Gorman et al. (1989 Virology 171:377-385). Briefly, cells were seeded to a density of 10 1.0 x 10⁶ per 10-cm dish and incubated overnight in DMEM containing 10% fetal calf serum (Gibco). 20 µg of receptor cDNA cloned into a cytomegalovirus promotor driven expression vector was mixed in 0.5 ml of 0.25 M CaCa₂, 0.5 ml of 2 x BBS (280 mM NaCl, 1.5 mM Na₂HPO₄, 50 mM BES, pH 6.96 and incubated for 30 min at room temperature. The calcium phosphate/DNA solution was then added to the cells, swirled gently, and incubated for 18 hours at 37°C under 3% CO₂. For ligand binding experiments, the cells were removed from the plate and 15 treated as described below.

To obtain VEGF conditioned media, cells were transfected in 15-cm dishes. Media was collected after 48 h and VEGF was partially purified by affinity chromatography using heparin High Trap TM columns (Pharmacia) and concentrated by ultrafiltration (Ferrara, N. and Henzel, W.J. 1989 Biochem. Biophys. Res. Comm. 161:851-858). The concentration of VEGF was determined by a ligand competition assay with bovine aortic 25 endothelial cells.

For autophosphorylation assays, cells were seeded in 6-well dishes (2x10³ cells per well), transfected as described above, and starved for 24 h in DMEM containing 0.5% fetal calf serum. The cells were then treated with 500 pM VEGF for 10 min. at 37°C or left untreated and 30 35 were subsequently lysed as described by Kris et al.

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(1985). Flk-1 was immunoprecipitated with an antiserum raised in rabbits against the C-terminus of the receptor. The immunoprecipitates were separated on a 7.5% SDS polyacrylamide gel, transferred to nitrocellulose, and 5 incubated with a mouse monoclonal antibody directed against phosphotyrosine (5E2; Fendly, B.M. et al., 1990 Cancer Research 50:1550-1558). Protein bands were visualized using horseradish peroxidase coupled goat anti-mouse antibody and the ECL™ (Amersham) detection 10 system.

6.1.8. RADIOIODINATION OF VEGF

Recombinant human VEGF (5 µg; generously provided by Dr. H. Weich) was dissolved in 110 µl sodium phosphate 15 buffer pH 7.6, and iodinated by the procedure of Hunter and Greenwood (1962). The reaction products were separated from the labeled protein by passage over a sephadex G50 column, pre-equilibrated with phosphate buffered saline (PBS) containing 0.7% bovine serum 20 albumin (BSA), and aliquots of the collected fractions were counted before and after precipitation with 20% trichloroacetic acid. The purity of the iodinated product was estimated to be superior to 90%, as determined by gel 25 electrophoresis, and the specific activity was 77000 cpm/ng. The bioactivity of the iodinated VEGF was confirmed by comparison with the bioactivities of native VEGF using the tissue factor introduction assay described by Clauss, M. et al. (1990 J. Exp. Med. 172:1535-1545).

30 6.1.9. CROSSLINKING OF VEGF TO Flk-1

COS-1 cells transiently expressing Flk-1 and untransfected COS-1 cells were incubated with 200 pM ¹²⁵I-VEGF at 4°C overnight, then washed twice with PBS and exposed to 0.5 mM disuccinimidyl suberate (DSS) in PBS 35 for 1 h at 4°C. The cells were lysed, Flk-1

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immunoprecipitated, and analyzed by electrophoresis on a 7% polytarcylamide gel followed by autoradiography.

6.1.10. VEGF BINDING

5 Ligand binding experiments were performed as described previously (Schumacher, R. et al., 1991, J. Biol. Chem. 266:19288-19295), COS-1 cells were grown in a 15-cm culture dish in DMEM for 48h after transfection. Cells were then washed carefully with PBS and incubated 10 with 5 ml of 25 mM EDTA in PBS for 10 min. Cells were then removed from the plate, washed once with binding buffer (DMEM, 25 mM HEPES, pH 7.5, 0.15% gelatin) and resuspended in 5 ml of binding buffer to determine the cell number. In a total volume of 500 μ l this cell 15 suspension was incubated for 90 min at 15°C with 10 pM 125 I-VEGF, and increasing concentration of unlabeled ligand (from 0 to 7×10^9), which was partially purified from conditioned media of COS-1 cells transiently expressing VEGF (164 amino acid form; Breier et al., 1992). After 20 incubation, cells were washed with PBS 0.1% PBS in the cold. Free ligand was removed by repeated centrifugation and resuspension in binding buffer. Finally, the 125 I radioactivity bound to the cells were determined in a gamma counter (Riastar). Data obtained were analyzed by 25 the method of Munson, P.J. and Rodbard, D. (1980 Anal. Biochem. 107:220-235).

6.1.11. RETROVIRAL VECTORS ENCODING TRANSDOMINANT-NEGATIVE MUTANTS OF Flk-1

30 Recombinant retroviral vectors were constructed that contained the coding region for amino acids 1 through 806 of the Flk-1 receptor (pLX Flk-1 cl.1 and cl.3, Figure 12). A recombinant virus containing a truncated c-fms 35 receptor mutant (pNTK cfms TM cl.7) was used as a control. To obtain virus producing cells mouse GPE cells

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were infected with amphotrophic virus-containing conditioned media of PA317 cells that had been transfected with recombinant retroviral DNA. C6 glioblastoma tumor cells were implanted into nude mice 5 either alone or coimplanted with virus producing cells. Injected cell numbers for the two sets of experiments are indicated below. Beginning at the time when the first tumors appeared, tumor volumes were measured every 2 to 3 days to obtain a growth curve.

10

Experiment No. 1

	Number of Mice	Number of C6 Cells	Virus-Producer Cell Line	Number of Virus-Cells
15	4	5×10^3	pLXSN Flk-1 TM cl.3	1×10^7
	4	5×10^3	None	0
	4	5×10^3	pNTK cfms TM cl.7	5×10^6

Experiment No. 2

	Number of Mice	Number of C6 Cells	Virus-Producer Cell Line	Number of Virus-Cells
20	4	2×10^4	pLXSN Flk-1 TM cl.1	2×10^7
	4	2×10^4	pLXSN Flk-1 TM cl.3	2×10^7
	4	2×10^4	None	0
	4	2×10^4	pNTK cfms TM cl.7	2×10^7

6.2. RESULTS6.2.1. ISOLATION OF Flk-1

To identify RTKs that are expressed during mouse 30 development, PCR assays using two degenerate oligonucleotide primer pools that were designed on the basis of highly conserved sequences within the kinase domain of RTKs were performed (Hanks, S.K. et al. 1988, Science 241:42-52). DNA extracted from a λgt10 cDNA library of day 8.5 mouse embryos (Fahrner, K. et al., 35

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1987, EMBO. J., 6:1497-1508), a stage in mouse development at which many differentiation processes begin was used as the template in the PCR assays. In a parallel approach, with the intention of identifying RTKs that regulate angiogenesis, similar primers were used for the amplification of RTK cDNA sequences from capillary endothelial cells that had been isolated from the brains of postnatal day 4-8 mice, a time at which brain endothelial cell proliferation is maximal (Robertson, 5 P.L. et al., 1985, Devel. Brain Res. 23:219-223). Both approaches yielded cDNA sequences (FIG. 11, SEQ. ID NO.:) encoding the recently described fetal liver RTK, Flk-1 (Matthews, W. et al., 1991, Proc. Natl. Acad. Sci. U.S.A. 88:9026-9030). Based on amino acid homology, this 10 receptor is a member of the type III subclass of RTKs (Ullrich, A. and Schlessinger, J. 1990, Cell 61:203-212) and is closely related to human flt, which also contains seven immunoglobin-like repeats in its extracellular domain in contrast to other RTKs of that subfamily, which 15 contain only five such repeat structures (Matthews, W. et al., 1991, Proc. Natl. Acad. Sci. U.S.A. 88:9026-9030). Sequence comparisons of Flk-1 with KDR (Terman, B.I. et al., 1991, Oncogene 6:1677-1683) and TKR-C (Sarzani, R. et al., 1992, Biochem. Biophys. Res. Comm. 186:706-714) 20 suggest that these are the human and rat homologues of Flk-1, respectively (Figure 1). 25

6.2.2 EXPRESSION OF Flk-1 mRNA DURING EMBRYONIC DEVELOPMENT

30 As a first step towards the elucidation of the biological function of Flk-1, the expression of Flk-1 mRNA was analyzed in mouse embryos at different development stages. Northern blot hybridization experiments indicated abundant expression of a major 5.5 35 kb mRNA between day 9.5 and day 18.5, with an apparent

decline towards the end of gestation (Figure 2A). In postnatal day 4-8 brain capillaries Flk-1 mRNA was found to be highly enriched compared to total brain mRNA (Figure 2B).

5 *In situ* hybridization experiments were performed to obtain more detailed information about the expression of Flk-1 during different embryonal stages. A single-stranded antisense, 2619-nucleotide-long DNA probe comprising the Flk-1 extracellular domain was used as a
10 probe because it generated the most specific hybridization signals. As an example, a parasagittal section of a day 14.5 embryo is shown in Figure 3. High levels of hybridization were detected in the ventricle of the heart, the lung, and the meninges; other tissues such
15 as brain, liver, and mandible appeared to contain fewer cells expressing Flk-1 mRNA. Thin strands of Flk-1 expression were also observed in the intersegmental regions of the vertebrae and at the inner surface of the atrium and the aorta. Higher magnification revealed that
20 the expression of Flk-1 seemed to be restricted to capillaries and blood vessels. Closer examination of the heart, for example, showed positive signals only in the ventricular capillaries and endothelial lining of the atrium (Figure 4A). In the lung, Flk-1 expression was
25 detected in peribronchial capillaries, but was absent from bronchial epithelium (Figure 4D). The aorta showed strong hybridization in endothelial cells, but not in the muscular layer (Figure 4C).

30 **6.2.3. EXPRESSION OF Flk-1 DURING ORGAN ANGIOGENESIS**
The neuroectoderm in the telencephalon of a day 11.5 mouse embryo is largely avascular; the first vascular sprouts begin to radially invade the organ originating from the perineural vascular plexus (Bär, J., 1980, Adv.
35 Anat. Embryol. Cell. Biol. 59:1-62; Risau, W. and Lemmon,

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v. 1988, Dev. Biol. 125:441-450). At this stage, expression of Flk-1 was high in the perineural vascular plexus and in invading vascular sprouts, as shown in Figure 5A. These *in situ* hybridization analyses indicated that the

5 proliferating endothelial cells of an angiogenic sprout expressed the Flk-1 mRNA. At day 14.5, when the neuroectoderm is already highly vascularized, numerous radial vessels as well as branching vessels of the intraneuronal plexus contained large amounts of Flk-1 mRNA
10 (Figure 5B). At postnatal day 4, when sprouting and endothelial cell proliferation is at its highest, strong expression of Flk-1 mRNA was observed in endothelial cells (Figure 5C). Conversely, in the adult brain when angiogenesis has ceased, Flk-1 expression was very low
15 (Figure 5D) and appeared to be restricted mainly to the choroid plexus (Figure 6). In the choroid plexus, cells in the inner vascular layer expressed Flk-1 mRNA, while epithelial cells did not (Figure 6A, B).

The embryonic kidney is vascularized by an
20 angiogenic process (Ekblom, P. et al., 1982, Cell Diff. 11:35-39). Glomerular and peritubular capillaries develop synchronously with epithelial morphogenesis. In the postnatal day 4 kidney, in addition to other capillaries, prominent expression of Flk-1 was observed
25 in the presumptive glomerular capillaries (Figure 7A). This expression persisted in the adult kidney (Figure 7C and D) and then seemed to be more confined to the glomerular compared to the early postnatal kidney.

30 6.2.4. Flk-1 EXPRESSION IN
ENDOTHELIAL CELL PROGENITORS

To investigate the possible involvement of Flk-1 in the early stages of vascular development, analysis of embryos at different stages during blood island formation
35 were performed. In a sagittal section of the deciduum of

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a day 8.5 mouse embryo, Flk-1 expression was detected on maternal blood vessels in the deciduum, in the yolk sac and in the trophectoderm. Flk-1 mRNA was also found in the allantois and inside the embryo, mainly located in 5 that part where mesenchyma is found (Figure 8A). At a higher magnification of the maternal deciduum, high levels of Flk-1 mRNA expression were found in the inner lining of blood vessels, which consist of endothelial cells (Figure 8B). In the yolk sac, hybridization 10 signals were confined to the mesodermal layer, in which the hemangioblasts differentiate (Figure 8C). Figure 8D shows a blood island at higher magnification, in which the peripheral angioblasts expressed a high level of Flk-1 mRNA.

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6.2.5. Flk-1 IS A HIGH AFFINITY RECEPTOR FOR VEGF

Detailed examination of in situ hybridization results and comparison with those for VEGF recently reported by Breier, G. et al. (1992, Development 114:521- 20 532) revealed a remarkable similarity in expression pattern. Furthermore, Flk-1 expression in the glomerular endothelium and VEGF in the surrounding epithelial cells (Breier, G. et al., 1992, Development 114:521-532) raised the possibility of a paracrine relationship between these 25 cells types and suggested therefore a ligand-receptor relationship for VEGF and Flk-1, respectively. In order to test this hypothesis, the full-length Flk-1 cDNA was cloned into the mammalian expression vector pCMV, which contains transcriptional control elements of the human 30 cytomegalovirus (Gorman, C.M. et al., 1989, Virology 171:377-385). For transient expression of the receptor, the Flk-1 expressing plasmid was then transfected into COS-1 fibroblasts.

Specific binding of VEGF to the Flk-1 RTK was 35 demonstrated by crosslinking and competition binding

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experiments. Purified 125 I-labeled VEGF was incubated with COS-1 cells transfected with the pCMV-Flk-1 expression vector. Crosslinking with DSS and subsequent analysis of immunoprecipitation, PAGE, and autoradiography revealed

- 5 an approximately 220 kD band which was not detected in the control experiment with untransfected COS-1 cells and is likely to represent the VEGF/Flk-1 receptor complex (Figure 9A). In addition, VEGF competed with 125 I-VEGF binding to Flk-1 expressing COS-1 cells (Figure 9B),
- 10 whereas untransfected COS-1 cells did not bind 125 I-VEGF. The interaction of VEGF with the receptor on transfected cells was specific, as PDGF-BB did not compete with binding of 125 I-VEGF. Analysis of the binding data revealed a K_d of about 10^{-10} M, suggesting that Flk-1 is a
- 15 high affinity receptor of VEGF. This finding, together with the Flk-1 and VEGF in situ hybridization results strongly suggests that Flk-1 is a physiologically relevantly receptor for VEGF.

An autophosphorylation assay was performed to

- 20 confirm the biological relevance of VEGF binding to the Flk-1 receptor. COS1 cells which transiently expressed Flk-1 were starved in DMEM containing 0.5% fetal calf serum for 24h, stimulated with 0.5 mM VEGF, and lysed. The receptors were immunoprecipitated with the Flk-1
- 25 specific polyclonal antibody CT128, and then analyzed by SDS-PAGE and subsequent immunoblotting using the antiphosphotyrosine antibody 5E2 (Fendly, B.M. et al., 1990, Cancer Research 50:1550-1558). As shown in Figure 10, VEGF stimulation of Flk-1 expressing cells led to a
- 30 significant induction of tyrosine phosphorylation of the 180 kD Flk-1 receptor.

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**6.2.6. INHIBITION OF TUMOR GROWTH BY
TRANSDOMINANT-NEGATIVE INHIBITION OF Flk-1**

The Flk-1 receptor is believed to play a major role in vasculogenesis and angiogenesis. Therefore, 5 inhibition of Flk-1 activity may inhibit vasculogenesis of a developing tumor and inhibit its growth. To test this hypothesis, tumor cells (C6 rat glioblastoma) and mouse cells producing a recombinant retrovirus encoding a truncated Flk-1 receptor were mixed and implanted 10 subcutaneously into nude mice. The implanted C6 glioblastoma cells secrete VEGF which will bind to and activate the Flk-1 receptors expressed on the surface of mouse endothelial cells. In the absence of any inhibitors of vasculogenesis, the endothelial cells will 15 proliferate and migrate towards the tumor cells. Alternatively, if at the time of injection, the tumor cells are co-injected with cells producing recombinant retrovirus encoding the dominant-negative Flk-1, the endothelial cells growing towards the implanted tumor 20 cells will become infected with recombinant retrovirus which may result in dominant-negative Flk-1 mutant expression and inhibition of endogenous Flk-1 signaling. Suppression of endothelial cell proliferation and 25 migration will result in failure of the implanted tumor cells to become vascularized which will lead to inhibition of tumor growth. As shown in Figures 12 and 13, tumor growth is significantly inhibited in mice receiving implantations of cells producing truncated Flk-1 indicating that expression of a truncated Flk-1 30 receptor can act in a dominant-negative manner to inhibit the activity of endogenous wild-type Flk-1.

The present invention is not to be limited in scope by the exemplified embodiments which are intended as illustrations of single aspects of the invention, and any 35 clones, DNA or amino acid sequences which are

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functionally equivalent are within the scope of the invention. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the 5 foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

It is also to be understood that all base pair sizes given for nucleotides are approximate and are used for 10 purposes of description.

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SEQUENCE LISTING

(1) GENERAL INFORMATION:

- (i) APPLICANT: Ullrich, et al
- (ii) TITLE OF INVENTION: FIX-1 IS A RECEPTOR FOR VASCULAR ENDOTHELIAL GROWTH FACTOR
- (iii) NUMBER OF SEQUENCES: 2
- (iv) CORRESPONDENCE ADDRESS:
 - (A) ADDRESSEE: Pennie & Edmonds
 - (B) STREET: 1155 Avenue of the Americas
 - (C) CITY: New York
 - (D) STATE: New York
 - (E) COUNTRY: U.S.A.
 - (F) ZIP: 10036-2711
- (v) COMPUTER READABLE FORM:
 - (A) MEDIUM TYPE: Floppy disk
 - (B) COMPUTER: IBM PC compatible
 - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
 - (D) SOFTWARE: PatentIn Release #1.0, Version #1.25
- (vi) CURRENT APPLICATION DATA:
 - (A) APPLICATION NUMBER: To be assigned
 - (B) FILING DATE: 03-MAR-1993
 - (C) CLASSIFICATION:
- (viii) ATTORNEY/AGENT INFORMATION:
 - (A) NAME: Coruzzi, Laura A.
 - (B) REGISTRATION NUMBER: 30,742
 - (C) REFERENCE/DOCKET NUMBER: 7683-034-999
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 - (C) TELEX: 66141 PENNIE

(2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 5470 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: unknown
 - (D) TOPOLOGY: unknown
- (ii) MOLECULE TYPE: DNA (genomic)

- (ix) FEATURE:
 - (A) NAME/KEY: CDS
 - (B) LOCATION: 286..4386

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

TATAGGGCGA ATTGGGTAGG GGACCCCCCT CGAGGTCGAC GGTATCGATA AGCTTGATAT	60
CGAATTCTGGG CCCAGACTGT GTCCCGCAGC CGGGATAACC TGGCTGACCC GATTCCCCGG	120
ACACCCGCTGA CAGCCGCCGGC TGGAGCCAGG GCGCCGGTGC CCCCGCTCT CCCCGGTCTT	180
GGGCTGCGGG GGCCATACCC CCTCTGTGAC TCTTTGCGG GCCAGGGACG GAGAAGGGAGT	240

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CTGTGCCCTGA GAAACTGGGC TCTGTCCCCA GGCGGGAGGT GCAGG ATG GAG ACC Met Glu Ser 1	294
AAG GCG CTG CTA GCT GTC GCT CTG TGG TTC TGC GTG GAG ACC CGA CCC Lys Ala Leu Leu Ala Val Ala Leu Trp Phe Cys Val Glu Thr Arg Ala 5 10 15	342
GCC TCT GTG GGT TTG ACT GGC GAT TTT CTC CAT CCC CCC AAG CTC AGC Ala Ser Val Gly Leu Thr Gly Asp Phe Leu His Pro Pro Lys Leu Ser 20 25 30 35	390
ACA CAG AAA GAC ATA CTG ACA ATT TTG GCA AAT ACA ACC CTT CAG ATT Thr Gln Lys Asp Ile Leu Thr Ile Leu Ala Asn Thr Thr Leu Gln Ile 40 45 50	438
ACT TGC AGG GGA CAG CCG GAC CTG GAC TGG CTT TCG CCC AAT GCT CAG Thr Cys Arg Gly Gln Arg Asp Leu Asp Trp Leu Trp Pro Asn Ala Gln 55 60 65	486
CGT GAT TCT GAG GAA AGG GTA TTG GTG ACT GAA TGC CCC GGT GGT GAC Arg Asp Ser Glu Glu Arg Val Leu Val Thr Glu Cys Gly Gly Asp 70 75 80	534
ACT ATC TTC TGC AAA ACA CTC ACC ATT CCC AGG GTG GTT GGA AAT GAT Ser Ile Phe Cys Lys Thr Leu Thr Ile Pro Arg Val Val Gly Asn Asp 85 90 95	582
ACT GGA GCC TAC AAG TGC TCG TAC CCG GAC GTC GAC ATA GCC TCC ACT Thr Gly Ala Tyr Lys Cys Ser Tyr Arg Asp Val Asp Ile Ala Ser Thr 100 105 110 115	630
GTT TAT GTC TAT GTT CGA CAT TAC AGA TCA CCA TTC ATC GCC TCT GTC Val Tyr Val Tyr Val Arg Asp Tyr Arg Ser Pro Phe Ile Ala Ser Val 120 125 130	678
AGT GAC CAG CAT GGC ATC GTG TAC ATC ACC GAG AAC AAG AAC AAA ACT Ser Asp Gln His Gly Ile Val Tyr Ile Thr Glu Asn Lys Asn Lys Thr 135 140 145	726
GTG GTG ATC CCC TGC CGA GGG TCG ATT TCA AAC CTC AAT GTG TCT CTT Val Val Ile Pro Cys Arg Gly Ser Ile Ser Asn Leu Asn Val Ser Leu 150 155 160	774
TGC GCT AGG TAT CCA GAA AAG AGA TTT GTT CCG GAT GGA AAC AGA ATT Cys Ala Arg Tyr Pro Glu Lys Arg Phe Val Pro Asp Gly Asn Arg Ile 165 170 175	822
TCC TGG GAC AGC GAG ATA GGC TTT ACT CTC CCC AGT TAC ATG ATC AGC Ser Trp Asp Ser Glu Ile Gly Phe Thr Leu Pro Ser Tyr Met Ile Ser 180 185 190 195	870
TAT CCC GGC ATG GTC TTC TGT GAG GCA AAG ATC AAT GAT GAA ACC TAT Tyr Ala Gly Met Val Phe Cys Glu Ala Lys Ile Asn Asp Glu Thr Tyr 200 205 210	918
CAG TCT ATC ATG TAC ATA GTT GTG GTT GAA TAT AGG ATT TAT GAT Gln Ser Ile Met Tyr Ile Val Val Val Gly Tyr Arg Ile Tyr Asp 215 220 225	966
GTG ATT CTG AGC CCC CGG CAT GAA ATT GAG CTA TCT CCC GGA GAA AAA Val Ile Leu Ser Pro Pro His Glu Ile Glu Leu Ser Ala Gly Glu Lys 230 235 240	1014
CTT GTC TTA AAT TGT ACA GCG AGA ACA GAG CTC AAT GTG GGG CTT GAT Leu Val Leu Asn Cys Thr Ala Arg Thr Glu Leu Asn Val Gly Leu Asp 245 250 255	1062

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TTC ACC TCG CAC TCT CCA CCT TCA AAG TCT CAT CAT AAG AAG ATT GTC Phe Thr Trp His Ser Pro Pro Ser Lys Ser His His Lys Lys Ile Val 260 265 270 275	1110
AAC CGG GAT GTG AAA CCC TTT CCT GGG ACT GTG GCG AAC ATG TTT TTG Asn Arg Asp Val Lys Pro Phe Pro Gly Thr Val Ala Lys Met Phe Leu 280 285 290 290	1158
AGC ACC TTG ACA ATA GAA AGT GTG ACC AAG AGT GAC CAA CGG GAA TAC Ser Thr Leu Thr Ile Glu Ser Val Thr Lys Ser Asp Gln Gly Glu Tyr 295 300 305 305	1206
ACC TGT GTC GCG TCC AGT GGA CGG ATG ATC AAG AGA AAT AGA ACA TTT Thr Cys Val Ala Ser Ser Gly Arg Met Ile Lys Arg Asn Arg Thr Phe 310 315 320 325	1254
GTC CGA GTT CAC ACA AAG CCT TTT ATT GCT TTC GGT AGT GGG ATG AAA Val Arg Val His Thr Lys Pro Phe Ile Ala Phe Gly Ser Gly Met Lys 325 330 335 335	1302
TCT TTG GTG GAA GCC ACA GTG GGC AGT CAA GTC CGA ATC CCT GTG AAG Ser Leu Val Glu Ala Thr Val Gly Ser Gln Val Arg Ile Pro Val Lys 340 345 350 355	1350
TAT CTC AGT TAC CCA GCT CCT GAT ATC AAA TGG TAC AGA AAT GGA AGG Tyr Leu Ser Tyr Pro Ala Pro Asp Ile Lys Trp Tyr Arg Asn Gly Arg 360 365 370 370	1398
CCC ATT GAG TCC AAC TAC ACA ATG ATT GTT GGC GAT GAA CTC ACC ATC Pro Ile Glu Ser Asn Tyr Thr Met Ile Val Gly Asp Glu Leu Thr Ile 375 380 385 385	1446
ATG GAA GTG ACT GAA AGA GAT GCA GCA AAC TAC ACG GTC ATC CTC ACC Met Glu Val Thr Glu Arg Asp Ala Gly Asn Tyr Thr Val Ile Leu Thr 390 395 400 400	1494
AAC CCC ATT TCA ATG GAG AAA CAG AGC CAC ATG GTC TCT CTG GTT GTG Asn Pro Ile Ser Met Glu Lys Gln Ser His Met Val Ser Leu Val Val 405 410 415 415	1542
AAT GTC CCA CCC CAG ATC GGT GAG AAA GCC TTG ATC TCG CCT ATG GAT Asn Val Pro Pro Gln Ile Gly Glu Lys Ala Leu Ile Ser Pro Met Asp 420 425 430 435	1590
TCC TAC CAG TAT CGG ACC ATG CAG ACA TTG ACA TGC ACA GTC TAC GCC Ser Tyr Gln Tyr Gly Thr Met Gln Thr Leu Thr Cys Thr Val Tyr Ala 440 445 450 450	1638
AAC CCT CCC CTG CAC CAC ATC CAG TCG TAC TGG CAG CTA GAA GAA CCC Asn Pro Pro Leu His His Ile Gln Trp Tyr Trp Gln Leu Glu Ala 455 460 465 465	1686
TGC TCC TAC AGA CCC CGC CAA ACA AGC CCG TAT GCT TGT AAA GAA TGG Cys Ser Tyr Arg Pro Gly Gln Thr Ser Pro Tyr Ala Cys Lys Glu Trp 470 475 480 480	1734
AGA CAC GTG GAG GAT TTC CAG GGG GGA AAC AAG ATC GAA GTC ACC AAA Arg His Val Glu Asp Phe Gln Gly Gly Asn Lys Ile Glu Val Thr Lys 485 490 495 495	1782
AAC CAA TAT GCC CTG ATT GAA GGA AAA AAC AAA ACT GTC ACT ACG CTG Asn Gln Tyr Ala Leu Ile Glu Gly Lys Asn Lys Thr Val Ser Thr Leu 500 505 510 515	1830
GTC ATC CAA CCT GCC AAC GTG TCA CGG TTG TAC AAA TGT GAA GCC ATC Val Ile Gln Ala Ala Asn Val Ser Ala Leu Tyr Lys Cys Glu Ala Ile 520 525 530 530	1878

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AAC AAA GCG GGA CGA GGA GAG AGG GTC ATC TCC TTC CAT GTC ATC AGG Asn Lys Ala Gly Arg Gly Glu Arg Val Ile Ser Phe His Val Ile Arg 535 540 545	1926
GCT CCT CAA ATT ACT GTG CAA CCT GCT CCC CAG CCA ACT GAG CAG GAG Gly Pro Glu Ile Thr Val Gln Pro Ala Ala Gln Pro Thr Glu Gln Glu 550 555 560	1974
AGT GTC TCC CTG TTG TGC ACT GCA GAC AGA AAT ACC TTT GAG AAC CTC Ser Val Ser Leu Leu Cys Thr Ala Asp Arg Asn Thr Phe Glu Asn Leu 565 570 575	2022
ACG TGG TAC AAG CTT GGC TCA CAG GCA ACA TCG GTC CAC ATG GGC GAA Thr Trp Tyr Lys Leu Gly Ser Gln Ala Thr Ser Val His Met Gly Glu 580 585 590 595	2070
TCA CTC ACA CCA GTT TGC AAG AAC TTG GAT GCT CTT TGG AAA CTG AAT Ser Leu Thr Pro Val Cys Lys Asn Leu Asp Ala Leu Trp Lys Leu Asn 600 605 610	2118
GCG ACC ATG TTT TCT AAC AGC ACA AAT GAC ATC TTG ATT GTG GCA TTT Gly Thr Met Phe Ser Asn Ser Thr Asn Asp Ile Leu Ile Val Ala Phe 615 620 625	2166
CAG AAT GCC TCT CTG CAG GAC CAA GGC GAC TAT GTT TGC TCT GCT CAA Gln Asn Ala Ser Leu Gln Asp Gly Asp Tyr Val Cys Ser Ala Gln 630 635 640	2214
GAT AAG AAG ACC AAG AAA AGA CAT TGC CTG GTC AAA CAG CTC ATC ATC Asp Lys Lys Thr Lys Lys Arg His Cys Leu Val Lys Gln Leu Ile Ile 645 650 655	2262
CTA GAG CGC ATG GCA CCC ATG ATC ACC GGA AAT CTG GAG AAT CAG ACA Leu Glu Arg Met Ala Pro Met Ile Thr Gly Asn Leu Glu Asn Gln Thr 660 665 670 675	2310
ACA ACC ATT GGC GAG ACC ATT GAA GTG ACT TGC CCA GCA TCT GGA AAT Thr Thr Ile Gly Glu Thr Ile Glu Val Thr Cys Pro Ala Ser Gly Asn 680 685 690	2358
CCT ACC CCA CAC ATT ACA TGG TTC AAA GAC AAC GAG ACC CTG GTA GAA Pro Thr Pro His Ile Thr Trp Phe Lys Asp Asn Glu Thr Leu Val Glu 695 700 705	2406
GAT TCA GGC ATT GTA CTG AGA GAT CGG AAC CCG AAC CTG ACT ATC CGC Asp Ser Gly Ile Val Leu Arg Asp Gly Asn Arg Asn Leu Thr Ile Arg 710 715 720	2454
AGG GTG AGG AAG GAG GAT GGA GGC CTC TAC ACC TGC CAG GCC TGC AAT Arg Val Arg Lys Glu Asp Gly Gly Leu Tyr Thr Cys Gln Ala Cys Asn 725 730 735	2502
GTC CTT CGC TGT GCA AGA CGG GAG AGC CTC TTC ATA ATA GAA GGT GCC Val Leu Gly Cys Ala Arg Ala Glu Thr Leu Phe Ile Ile Glu Gly Ala 740 745 750 755	2550
CAG GAA AAG ACC AAC TTG GAA GTC ATT ATC CTC GTC GGC ACT GCA GTG Gln Glu Lys Thr Asn Leu Glu Val Ile Ile Leu Val Gly Thr Ala Val 760 765 770	2598
ATT GCC ATG TTC TTG CTC CTT CTT GTC ATT GTC CTA CGG ACC GTT Ile Ala Met Phe Phe Trp Leu Leu Leu Val Ile Val Leu Arg Thr Val 775 780 785	2646
AAG CGG GCC AAT GAA GGG GAA CTG AAG ACA GGC TAC TTG TCT ATT GTC Lys Arg Ala Asn Glu Gly Glu Leu Lys Thr Gly Tyr Leu Ser Ile Val 790 795 800	2694

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ATG GAT CCA GAT GAA TTG CCC TTG GAT GAG CCC TGT GAA CGC TTG CCT Met Asp Pro Asp Glu Leu Pro Leu Asp Glu Arg Cys Glu Arg Leu Pro 805 810 815	2742
TAT GAT GCC AGC AAG TGG GAA TTC CCC AGG GAC CGG CTG AAA CTA GGA Tyr Asp Ala Ser Lys Trp Glu Phe Pro Arg Asp Arg Leu Lys Leu Gly 820 825 830 835	2790
AAA CCT CTT GGC CCC GGT GCC TTC GGC CAA GTG ATT GAG GCA GAC GCT Lys Pro Leu Gly Arg Gly Ala Phe Gly Gln Val Ile Glu Ala Asp Ala 840 845 850	2838
TTT GGA ATT GAC AAG ACA GCG ACT TGG AAA ACA GTC GCC GTC AAG ATG Phe Gly Ile Asp Lys Thr Ala Thr Cys Lys Thr Val Ala Val Lys Met 855 860 865	2886
TTG AAA GAA GGA GCA ACA CAC AGC GAG CAT CGA GCC CTC ATC TCT GAA Leu Lys Glu Gly Ala Thr His Ser Glu His Arg Ala Leu Met Ser Glu 870 875 880	2934
CTC AAG ATC CTC ATC CAC ATT GGT CAC CAT CTC AAT GTG GTG AAC CTC Leu Lys Ile Leu Ile His Ile Gly His His Leu Asn Val Val Asn Leu 885 890 895	2982
CTA GGC GCC TGC ACC AAG CCC GGA GGG CCT CTC ATG GTG ATT GTG GAA Leu Gly Ala Cys Thr Lys Pro Gly Gly Pro Leu Met Val Ile Val Glu 900 905 910 915	3030
TTC TGC AAG TTT GGA AAC CTA TCA ACT TAC TTA CGG GGC AAG AGA AAT Phe Cys Lys Phe Gly Asn Leu Ser Thr Tyr Leu Arg Gly Lys Arg Asn 920 925 930	3078
GAA TTT GTT CCC TAT AAG AGC AAA GGG GCA CGC TTC CGC CAG GGC AAG Glu Phe Val Pro Tyr Lys Ser Lys Gly Ala Arg Phe Arg Gln Gly Lys 935 940 945	3126
GAC TAC GTT GGG GAG CTC TCC GTG GAT CTG AAA AGA CGC TTG GAC AGC Asp Tyr Val Gly Glu Leu Ser Val Asp Leu Lys Arg Arg Leu Asp Ser 950 955 960	3174
ATC ACC AGC AGC CAG AGC TCT GCC AGC TCA CGC TTT GTT GAG GAG AAA Ile Thr Ser Ser Gln Ser Ser Ala Ser Ser Gly Phe Val Glu Glu Lys 965 970 975	3222
TCG CTC AGT GAT GTA GAG GAA GAA GCT TCT GAA GAA CTG TAC AAG Ser Leu Ser Asp Val Glu Glu Glu Ala Ser Glu Glu Leu Tyr Lys 980 985 990 995	3270
GAC TTC CTG ACC TTG GAG CAT CTC ATC TGT TAC AGC TTC CAA GTG GCT Asp Phe Leu Thr Leu Glu His Leu Ile Cys Tyr Ser Phe Gln Val Ala 1000 1005 1010	3318
AAG GGC ATG GAG TTC TTG GCA TCA AGG AAG TGT ATC CAC AGG GAC CTG Lys Gly Met Glu Phe Leu Ala Ser Arg Lys Cys Ile His Arg Asp Leu 1015 1020 1025	3366
GCA GCA CGA AAC ATT CTC CTA TCG GAG AAG ATT GTG GTT AAG ATC TGT Ala Ala Arg Asn Ile Leu Leu Ser Glu Lys Asn Val Val Lys Ile Cys 1030 1035 1040	3414
GAC TTC GGC TTG GCC CGG GAC ATT TAT AAA GAC CGG GAT TAT GTC AGA Asp Phe Gly Leu Ala Arg Asp Ile Tyr Lys Asp Pro Asp Tyr Val Arg 1045 1050 1055	3462
AAA CGA GAT GCC CGA CTC CCT TTG AAG TGG ATC GCC CGG GAA ACC ATT Lys Gly Asp Ala Arg L u Pr Leu Lys Trp Met Ala Pr Glu Thr Ile 1060 1065 1070 1075	3510

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TTT GAC AGA GTA TAC ACA ATT CAG ACC GAT GTG TGG TCT TTC GGT GTC Phe Asp Arg Val Tyr Thr Ile Gln Ser Asp Val Trp Ser Phe Gly Val 1080 1085 1090	3558
TTG CTC TGG GAA ATA TTT TCC TTA GGT GCC TCC CCA TAC CCT GGG GTC Leu Leu Trp Glu Ile Phe Ser Leu Gly Ala Ser Pro Tyr Pro Gly Val 1095 1100 1105	3606
AAG ATT GAT GAA GAA TTT TGT AGG AGA TTG AAA GAA GGA ACT AGA ATG Lys Ile Asp Glu Glu Phe Cys Arg Arg Leu Lys Glu Gly Thr Arg Met 1110 1115 1120	3654
CGG GCT CCT GAC TAC ACT ACC CCA GAA ATG TAC CAG ACC ATG CTG GAC Arg Ala Pro Asp Tyr Thr Pro Glu Met Tyr Gln Thr Met Leu Asp 1125 1130 1135	3702
TGC TGG CAT GAG GAC CCC AAC CAG AGA CCC TCG TTT TCA GAG TTG GTG Cys Trp His Glu Asp Pro Asn Gln Arg Pro Ser Phe Ser Glu Leu Val 1140 1145 1150 1155	3750
GAG CAT TTG GGA AAC CTC CTG CAA GCA AAT GCG CAG CAG GAT GGC AAA Glu His Leu Gly Asn Leu Leu Gln Ala Asn Ala Gln Asp Gly Lys 1160 1165 1170	3798
GAC TAT ATT GTT CTT CCA ATG TCA GAG ACA CTG AGC ATG GAA GAG GAT Asp Tyr Ile Val Leu Pro Met Ser Glu Thr Leu Ser Met Glu Glu Asp 1175 1180 1185	3846
TCT GGA CTC TCC CTG CCT ACC TCA CCT GTT TCC TGT ATG GAG GAA GAG Ser Gly Leu Ser Leu Pro Thr Ser Pro Val Ser Cys Met Glu Glu Glu 1190 1195 1200	3894
GAA GTG TGC GAC CCC AAA TTC CAT TAT GAC AAC ACA GCA GGA ATC AGT Glu Val Cys Asp Pro Lys Phe His Tyr Asp Asn Thr Ala Gly Ile Ser 1205 1210 1215	3942
CAT TAT CTC CRG AAC AGT AAG CGA AAG AGC CGG CCA GTG AGT GTA AAA His Tyr Leu Gln Asn Ser Lys Arg Lys Ser Arg Pro Val Ser Val Lys 1220 1225 1230 1235	3990
ACA TTT GAA GAT ATC CCA TTG GAG GAA CCA GAA GTA AAA GTG ATC CCA Thr Phe Glu Asp Ile Pro Leu Glu Pro Glu Val Lys Val Ile Pro 1240 1245 1250	4038
GAT GAC ACC CAG ACA GAC AGT GGG ATG GTC CTT GCA TCA GAA GAG CTG Asp Asp Ser Gln Thr Asp Ser Gly Met Val Leu Ala Ser Glu Glu Leu 1255 1260 1265	4086
AAA ACT CTG GAA GAC AGG AAC AAA TTA TCT CCA TCT TTT GGT GGA ATG Lys Thr Leu Glu Asp Arg Asn Lys Leu Ser Pro Ser Phe Gly Gly Met 1270 1275 1280	4134
ATG CCC AGT AAA ACC AGG GAG TCT GTG GCC TCG GAA GGC TCC AAC CAG Met Pro Ser Lys Ser Arg Glu Ser Val Ala Ser Glu Gly Ser Asn Gln 1285 1290 1295	4182
ACC AGT CGC TAC CAG TCT GGG TAT CAC TCA GAT GAC ACA GAC ACC ACC Thr Ser Gly Tyr Gln Ser Gly Tyr His Ser Asp Asp Thr Asp Thr Thr 1300 1305 1310 1315	4230
GTG TAC TCC ACC GAC GAG GCA GGA CTT TTA AAG ATG GTG GAT GCT GCA Val Tyr Ser Ser Asp Glu Ala Gly Leu Leu Lys Met Val Asp Ala Ala 1320 1325 1330	4278
GTT CAC GCT GAC TCA GGG ACC ACA CTG CAG CTC ACC TCC TGT TTA AAT Val His Ala Asp Ser Gly Thr Thr Leu Gln Leu Thr Ser Cys Leu Asn 1335 1340 1345	4326

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CGA ACT GGT CCT GTC CCG GCT CCG CCC CCA ACT CCT GGA AAT CAC GAG Gly Ser Gly Pro Val Pr Ala Pro Pro Pro Thr Pro Gly Asn His Glu 1350 1355 1360	4374
AGA GGT GCT GCT TAGATTTCA AGTGTGTT C TTCCACAC CGCGAAGTAG Arg Gly Ala Ala 1365	4426
CCACATTG A TTTCA TTT TGGAGGAGGG ACCTCAGACT GCAAGGAGCT TGTCTCAGG	4486
GCATTTCCAG AGAAGATGCC CATGACCCAA GAATGTGTT ACTCTACTCT CTTTCCATT	4546
CATTTAAAAG TCCATATATAA TGTGCCCTGC TGTGGTCTCA CTACCACTTA AAGCAAAAGA	4606
CTTTCAAACA CGTGGACTCT GTCTCCAAG AAGTGGCAAC GGCACCTCTG TGAAACTGGA	4666
TCGAATGGGC AATGCTTTGT GTGTTGAGGA TGGGTGAGAT GTCCCAGGGC CGAGTCTGTC	4726
TACCTTGGAG GCTTTGTGGA GGATGCGGGC TATGAGCAA GTGTTAAGTG TGGGATGTGG	4786
ACTGGGAGGA AGGAAGGGCC AAGTCGCTCG GAGACCGGTT GGAGCTGCA GATGCATTGT	4846
GCTGGCTCTG GTGGAGGTGG CCTTGTGGCC TGTCAAGAAA CGCRAAGGGC GCCGGCAGGG	4906
TTTGGTTTG GAGGTTTGC GTGCTCTCA CAGTCGGTT ACAGGGAGT TCCCTGTGGC	4966
GTTTCCTACT CCTAATGAGA GTTCCCTCCG GACTCTTACG TGTCTCTGG CCTGGCCCCA	5026
GGAAAGGAAAT GATGCAGCTT GCTCCTTCCT CATCTCTCAG CCTGTGCCCT AATTCAAGAAC	5086
ACCAAAAGAG AGGAACGTG GCAAGAGGTC C TGACGGGGC CGAAGAAITG TGAGAACAGA	5146
ACAGAAACTC AGGGTTCTG CTGGGTGGAG ACCCACGTGG CCCCTGGTG GCAGGGCTG	5206
GGGTTCTCTG TCAAGTGGCG GTAAAGGCTC AGGCTGGTGT TCTTCCCTCA TCTCCACTCC	5266
TGTCAAGGCC CCAAGTCCTC AGTATTTAG CTTTGTGGCT TCTGTGATGGC AGAAAAATCT	5326
TAATTGGTTG GTTGCTCTC CAGATAATCA CTAGCCAGAT TTGAAATTAA CTTTTAGCC	5386
GAGGTTATGA TAACATCTAC TGTATCCITT AGAATTTAA CCTATAAAAC TATGTCTACT	5446
GGTTTCTGCC TGTGTGCTTA TGTT	5470

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 1367 amino acids
 (B) TYPE: amino acid
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Glu Ser Lys Ala Leu Leu Ala Val Ala Leu Trp Phe Cys Val Glu 1 5 10 15
Thr Arg Ala Ala Ser Val Gly Leu Thr Gly Asp Phe Leu His Pro Pro 20 25 30
Lys Leu Ser Thr Gln Lys Asp Ile Leu Thr Ile Leu Ala Asn Thr Thr 35 40 45
Leu Gln Ile Thr Cys Arg Gly Gln Arg Asp Leu Asp Trp Leu Trp Pro 50 55 60

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Asn Ala Gln Arg Asp Ser Glu Glu Arg Val Leu Val Thr Glu Cys Gly
 65 70 75 80
 Gly Gly Asp Ser Ile Phe Cys Lys Thr Leu Thr Ile Pro Arg Val Val
 85 90 95
 Gly Asn Asp Thr Gly Ala Tyr Lys Cys Ser Tyr Arg Asp Val Asp Ile
 100 105 110
 Ala Ser Thr Val Tyr Val Tyr Val Arg Asp Tyr Arg Ser Pro Phe Ile
 115 120 125
 Ala Ser Val Ser Asp Gln His Gly Ile Val Tyr Ile Thr Glu Asn Lys
 130 135 140
 Asn Lys Thr Val Val Ile Pro Cys Arg Gly Ser Ile Ser Asn Leu Asn
 145 150 155 160
 Val Ser Leu Cys Ala Arg Tyr Pro Glu Lys Arg Phe Val Pro Asp Gly
 165 170 175
 Asn Arg Ile Ser Trp Asp Ser Glu Ile Gly Phe Thr Leu Pro Ser Tyr
 180 185 190
 Met Ile Ser Tyr Ala Gly Met Val Phe Cys Glu Ala Lys Ile Asn Asp
 195 200 205
 Glu Thr Tyr Gln Ser Ile Met Tyr Ile Val Val Val Val Gly Tyr Arg
 210 215 220
 Ile Tyr Asp Val Ile Leu Ser Pro Pro His Glu Ile Glu Leu Ser Ala
 225 230 235 240
 Gly Glu Lys Leu Val Leu Asn Cys Thr Ala Arg Thr Glu Leu Asn Val
 245 250 255
 Gly Leu Asp Phe Thr Trp His Ser Pro Pro Ser Lys Ser His His Lys
 260 265 270
 Lys Ile Val Asn Arg Asp Val Lys Pro Phe Pro Gly Thr Val Ala Lys
 275 280 285
 Met Phe Leu Ser Thr Leu Thr Ile Glu Ser Val Thr Lys Ser Asp Gln
 290 295 300
 Gly Glu Tyr Thr Cys Val Ala Ser Ser Gly Arg Met Ile Lys Arg Asn
 305 310 315 320
 Arg Thr Phe Val Arg Val His Thr Lys Pro Phe Ile Ala Phe Gly Ser
 325 330 335
 Gly Met Lys Ser Leu Val Glu Ala Thr Val Gly Ser Gln Val Arg Ile
 340 345 350
 Pro Val Lys Tyr Leu Ser Tyr Pro Ala Pro Asp Ile Lys Trp Tyr Arg
 355 360 365
 Asn Gly Arg Pro Ile Glu Ser Asn Tyr Thr Met Ile Val Gly Asp Glu
 370 375 380
 Leu Thr Ile Met Glu Val Thr Glu Arg Asp Ala Gly Asn Tyr Thr Val
 385 390 395 400
 Ile Leu Thr Asn Pro Ile Ser Met Glu Lys Gln Ser His Met Val Ser
 405 410 415
 Leu Val Val Asn Val Pro Pro Gln Ile Gly Glu Lys Ala Leu Ile Ser

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420	425	430
Pro Met Asp Ser Tyr Gln Tyr Gly Thr Met Gln Thr Leu Thr Cys Thr		
435	440	445
Val Tyr Ala Asn Pro Pro Leu His His Ile Gln Trp Tyr Trp Gln Leu		
450	455	460
Glu Glu Ala Cys Ser Tyr Arg Pro Gly Gln Thr Ser Pro Tyr Ala Cys		
465	470	475
Lys Glu Trp Arg His Val Glu Asp Phe Gln Gly Gly Asn Lys Ile Glu		
485	490	495
Val Thr Lys Asn Gln Tyr Ala Leu Ile Glu Gly Lys Asn Lys Thr Val		
500	505	510
Ser Thr Leu Val Ile Gln Ala Ala Asn Val Ser Ala Leu Tyr Lys Cys		
515	520	525
Glu Ala Ile Asn Lys Ala Gly Arg Gly Glu Arg Val Ile Ser Phe His		
530	535	540
Val Ile Arg Gly Pro Glu Ile Thr Val Gln Pro Ala Ala Gln Pro Thr		
545	550	555
560		
Glu Gln Glu Ser Val Ser Leu Leu Cys Thr Ala Asp Arg Asn Thr Phe		
565	570	575
Glu Asn Leu Thr Trp Tyr Lys Leu Gly Ser Gln Ala Thr Ser Val His		
580	585	590
Met Gly Glu Ser Leu Thr Pro Val Cys Lys Asn Leu Asp Ala Leu Trp		
595	600	605
Lys Leu Asn Gly Thr Met Phe Ser Asn Ser Thr Asn Asp Ile Leu Ile		
610	615	620
Val Ala Phe Gln Asn Ala Ser Leu Gln Asp Gln Gly Asp Tyr Val Cys		
625	630	635
640		
Ser Ala Gln Asp Lys Lys Thr Lys Lys Arg His Cys Leu Val Lys Gln		
645	650	655
Leu Ile Ile Leu Glu Arg Met Ala Pro Met Ile Thr Gly Asn Leu Glu		
660	665	670
Asn Gln Thr Thr Ile Gly Glu Thr Ile Glu Val Thr Cys Pro Ala		
675	680	685
Ser Gly Asn Pro Thr Pro His Ile Thr Trp Phe Lys Asp Asn Glu Thr		
690	695	700
Leu Val Glu Asp Ser Gly Ile Val Leu Arg Asp Gly Asn Arg Asn Leu		
705	710	715
720		
Thr Ile Arg Arg Val Arg Lys Glu Asp Gly Gly Leu Tyr Thr Cys Gln		
725	730	735
Ala Cys Asn Val Leu Gly Cys Ala Arg Ala Glu Thr Leu Phe Ile Ile		
740	745	750
Glu Gly Ala Gln Glu Lys Thr Asn Leu Glu Val Ile Ile Leu Val Gly		
755	760	765
Thr Ala Val Ile Ala Met Phe Phe Trp Leu Leu Leu Val Ile Val Leu		
770	775	780

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Arg Thr Val Lys Arg Ala Asn Glu Gly Glu Leu Lys Thr Gly Tyr Leu
 785 790 795 800

Ser Ile Val Met Asp Pro Asp Glu Leu Pro Leu Asp Glu Arg Cys Glu
 805 810 815

Arg Leu Pro Tyr Asp Ala Ser Lys Trp Glu Phe Pro Arg Asp Arg Leu
 820 825 830

Lys Leu Gly Lys Pro Leu Gly Arg Gly Ala Phe Gly Gln Val Ile Glu
 835 840 845

Ala Asp Ala Phe Gly Ile Asp Lys Thr Ala Thr Cys Lys Thr Val Ala
 850 855 860

Val Lys Met Leu Lys Glu Gly Ala Thr His Ser Glu His Arg Ala Leu
 865 870 875 880

Met Ser Glu Leu Lys Ile Leu Ile His Ile Gly His His Leu Asn Val
 885 890 895

Val Asn Leu Leu Gly Ala Cys Thr Lys Pro Gly Gly Pro Leu Met Val
 900 905 910

Ile Val Glu Phe Cys Lys Phe Gly Asn Leu Ser Thr Tyr Leu Arg Gly
 915 920 925

Lys Arg Asn Glu Phe Val Pro Tyr Lys Ser Lys Gly Ala Arg Phe Arg
 930 935 940

Gln Gly Lys Asp Tyr Val Gly Glu Leu Ser Val Asp Leu Lys Arg Arg
 945 950 955 960

Leu Asp Ser Ile Thr Ser Ser Gln Ser Ser Ala Ser Ser Gly Phe Val
 965 970 975

Glu Glu Lys Ser Leu Ser Asp Val Glu Glu Glu Glu Ala Ser Glu Glu
 980 985 990

Leu Tyr Lys Asp Phe Leu Thr Leu Glu His Leu Ile Cys Tyr Ser Phe
 995 1000 1005

Gln Val Ala Lys Gly Met Glu Phe Leu Ala Ser Arg Lys Cys Ile His
 1010 1015 1020

Arg Asp Leu Ala Ala Arg Asn Ile Leu Leu Ser Glu Lys Asn Val Val
 1025 1030 1035 1040

Lys Ile Cys Asp Phe Gly Leu Ala Arg Asp Ile Tyr Lys Asp Pro Asp
 1045 1050 1055

Tyr Val Arg Lys Gly Asp Ala Arg Leu Pro Leu Lys Trp Met Ala Pro
 1060 1065 1070

Glu Thr Ile Phe Asp Arg Val Tyr Thr Ile Gln Ser Asp Val Trp Ser
 1075 1080 1085

Phe Gly Val Leu Leu Trp Glu Ile Phe Ser Leu Gly Ala Ser Pro Tyr
 1090 1095 1100

Pro Gly Val Lys Ile Asp Glu Glu Phe Cys Arg Arg Leu Lys Glu Gly
 1105 1110 1115 1120

Thr Arg Met Arg Ala Pro Asp Tyr Thr Thr Pr Glu Met Tyr Gln Thr
 1125 1130 1135

Met Leu Asp Cys Trp His Glu Asp Pro Asn Gln Arg Pro Ser Phe Ser

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1140

1145

1150

Glu Leu Val Glu His Leu Gly Asn Leu Leu Gln Ala Asn Ala Gln Gln
1155 1160 1165

Asp Gly Lys Asp Tyr Ile Val Leu Pro Met Ser Glu Thr Leu Ser Met
1170 1175 1180

Glu Glu Asp Ser Gly Leu Ser Leu Pro Thr Ser Pro Val Ser Cys Met
1185 1190 1195 1200

Glu Glu Glu Val Cys Asp Pro Lys Phe His Tyr Asp Asn Thr Ala
1205 1210 1215

Gly Ile Ser His Tyr Leu Gln Asn Ser Lys Arg Lys Ser Arg Pro Val
1220 1225 1230

Ser Val Lys Thr Phe Glu Asp Ile Pro Leu Glu Glu Pro Glu Val Lys
1235 1240 1245

Val Ile Pro Asp Asp Ser Gln Thr Asp Ser Gly Met Val Leu Ala Ser
1250 1255 1260

Glu Glu Leu Lys Thr Leu Glu Asp Arg Asn Lys Leu Ser Pro Ser Phe
1265 1270 1275 1280

Gly Gly Met Met Pro Ser Lys Ser Arg Glu Ser Val Ala Ser Glu Gly
1285 1290 1295

Ser Asn Gln Thr Ser Gly Tyr Gln Ser Gly Tyr His Ser Asp Asp Thr
1300 1305 1310

Asp Thr Thr Val Tyr Ser Ser Asp Glu Ala Gly Leu Leu Lys Met Val
1315 1320 1325

Asp Ala Ala Val His Ala Asp Ser Gly Thr Thr Leu Gln Leu Thr Ser
1330 1335 1340

Cys Leu Asn Gly Ser Gly Pro Val Pro Ala Pro Pro Pro Thr Pro Gly
1345 1350 1355 1360

Asn His Glu Arg Gly Ala Ala
1365

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WHAT IS CLAIMED IS:

1. A recombinant DNA vector containing a nucleotide sequence that encodes a Flk-1 operatively associated with a regulatory sequence that controls gene expression in a host.
5
2. A recombinant DNA vector containing a nucleotide sequence that encodes a Flk-1 fusion protein operatively associated with a regulatory sequence that controls gene expression in a host.
10
3. An engineered host cell that contains the recombinant DNA vector of Claims 1 or 2.
15
4. An engineered cell line that contains the recombinant DNA expression vector of Claim 1 and expresses Flk-1.
20
5. The engineered cell line of Claim 3 which expresses the Flk-1 on the surface of the cell.
25
6. An engineered cell line that contains the recombinant DNA expression vector of Claim 2 and expresses the Flk-1 fusion protein.
30
7. The engineered cell line of Claim 6 that expresses the Flk-1 fusion protein on the surface of the cell.
35
8. A method for producing recombinant Flk-1, comprising:
 - (a) culturing a host cell transformed with the recombinant DNA expression vector of Claim 1 and which expresses the Flk-1; and

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(b) recovering the Flk-1 gene product from the cell culture.

9. A method for producing recombinant Flk-1 fusion protein, comprising:

(a) culturing a host cell transformed with the recombinant DNA expression vector of Claim 2 and which expresses the Flk-1 fusion protein; and

10 (b) recovering the Flk-1 fusion protein from the cell culture.

10. An isolated recombinant Flk-1 receptor protein.

15 11. A fusion protein comprising Flk-1 linked to a heterologous protein or peptide sequence.

12. An oligonucleotide which encodes an antisense sequence complementary to a portion of the Flk-1 20 nucleotide sequence, and which inhibits translation of the Flk-1 gene in a cell.

13. The oligonucleotide of Claim 12 which is complementary to a nucleotide sequence encoding the amino 25 terminal region of the Flk-1.

14. A monoclonal antibody which immunospecifically binds to an epitope of the Flk-1.

30 15. The monoclonal antibody of Claim 14 which competitively inhibits the binding of VEGF to the Flk-1.

35 16. The monoclonal antibody of Claim 14 which is linked to a cytotoxic agent.

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17. The monoclonal antibody of Claim 14 which is linked to a radioisotope.

18. A method for screening and identifying 5 antagonists of VEGF, comprising:

- (a) contacting a cell line that expresses Flk-1 with a test compound in the presence of VEGF; and
- (b) determining whether the test compound 10 inhibits the binding and cellular effects of VEGF on the cell line,

in which antagonists are identified as those compounds that inhibit both the binding and cellular effects of VEGF on the cell line.

15 19. A method for screening and identifying agonists of VEGF, comprising:

- (a) contacting a cell line that expresses the Flk-1 with a test compound in the presence and in the absence of VEGF;
- (b) determining whether, in the presence of 20 VEGF, the test compound inhibits the binding of VEGF to the cell line; and
- (c) determining whether, in the absence of the VEGF, the test compound mimics the 25 cellular effects of VEGF on the cell line,

in which agonists are identified as those test compounds that inhibit the binding but mimic the cellular effects of VEGF on the cell line.

30 20. The method according to Claims 18 or 19 in which the cell line is a genetically engineered cell line.

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21. The method according to Claims 18 or 19 in which the cell line endogenously expresses the Flk-1.

22. A method for screening and identifying
5 antagonists of VEGF comprising:

- (a) contacting Flk-1 protein with a random peptide library such that Flk-1 will recognize and bind to one or more peptide species within the library;
- 10 (b) isolating the Flk-1/peptide combination;
- (c) determining the sequence of the peptide isolated in step c; and
- (d) determining whether the test compound inhibits the binding and cellular effects
15 of VEGF,

in which antagonists are identified as those peptides that inhibit both the binding and cellular effects of VEGF.

20 23. A method for screening and identifying agonists of VEGF comprising:

- (a) contacting Flk-1 protein with a random peptide library such that Flk-1 will recognize and bind to one or more peptide species within the library;
- 25 (b) isolating the Flk-1/peptide combination;
- (c) determining the sequence of the peptide isolated in step c; and
- (d) determining whether, in the absence of the
30 VRGF, the peptide mimics the cellular effects of VEGF,

in which agonists are identified as those peptides that inhibit the binding but mimic the cellular effects of Flk-1.

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24. The method according to Claims 22 or 23 in which the Flk-1 protein is genetically engineered.

25. A method of modulating the endogenous enzymatic activity of the tyrosine kinase Flk-1 receptor in a mammal comprising administering to the mammal an effective amount of a ligand to the Flk-1 receptor protein to modulate the enzymatic activity.

10 26. The method of Claim 25 in which the ligand to the Flk-1 receptor is VEGF.

27. The method of Claim 25 in which the ligand to the Flk-1 receptor is a VEGF agonist.

15 28. The method of Claim 25 in which the ligand to the Flk-1 receptor is an antagonist of VEGF.

29. The antagonist of Claim 28 that is a monoclonal antibody which immunospecifically binds to an epitope of Flk-1.

30. The antagonist of Claim 28 that is a soluble Flk-1 receptor.

25 31. The method of Claim 25 in which the enzymatic activity of the receptor protein is increased.

30 32. The method of Claim 25 in which the enzymatic activity of the receptor protein is decreased.

33. The method of Claim 31 in which the ligand stimulates endothelial cell proliferation.

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34. The method of Claim 32 in which the ligand inhibits endothelial cell proliferation.

35. The method of Claim 32 in which the ligand 5 inhibits angiogenesis.

36. A recombinant vector containing a nucleotide sequence that encodes a truncated Flk-1 which has dominant-negative activity which inhibits the cellular 10 effects of VEGF binding.

37. The recombinant vector of claim 36 containing a nucleotide sequence encoding amino acids 1 through 806 of Flk-1.

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38. The recombinant vector of claim 36 in which the vector is a retrovirus vector.

39. The recombinant vector of claim 38 containing 20 a nucleotide sequence encoding amino acids 1 through 806 of Flk-1.

40. An engineered cell line that contains the recombinant DNA vector of Claim 36 and expresses 25 truncated Flk-1.

41. An engineered cell line that contains the recombinant vector of Claim 38 or 39 and produces 30 infectious retrovirus particles expressing truncated Flk-1.

42. An isolated recombinant truncated Flk-1 receptor protein which has dominant-negative activity which inhibits the cellular effects of VEGF binding.

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43. A method of modulating the cellular effects of VEGF in a mammal comprising administrating to the mammal an effective amount of truncated Flk-1 receptor protein which inhibits the cellular effects of VEGF binding.

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FLK-1	866	ILIHIGHAIVNVNLLGACTKPGGPLMWIVEFSKFGNLSTYLRKRNRFVPYKSKGARRQ	
KDR			C—D—S—T—S—
TKR-C			C—C—S—
FLK-1	926	GKDYVGEELSYDLKRRLDSTSSQSSASSGFVEEKSLSDVEEEASEEELYKDFLTLEHLIC	
KDR			AIP—P—D—
TKR-C			
FLK-1	986	YSFQVAKCNEFLASRKCIHRDLAARNILLSEKNWKICDFGLARDIYKOPDVMRKGDARL	
KDR			
TKR-C			

FIG. 1

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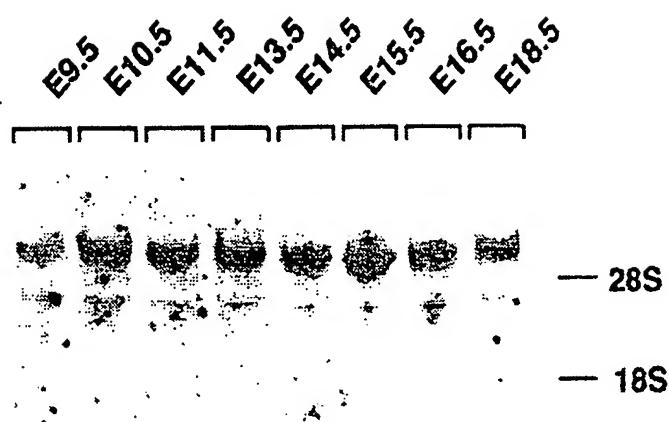


FIG. 2A

P4 brain
ad. brain
capillaries



— 9.5 kb
— 7.5 kb
— 4.4 kb

— GAPDH

FIG. 2B



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FIG. 3A

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FIG. 3B

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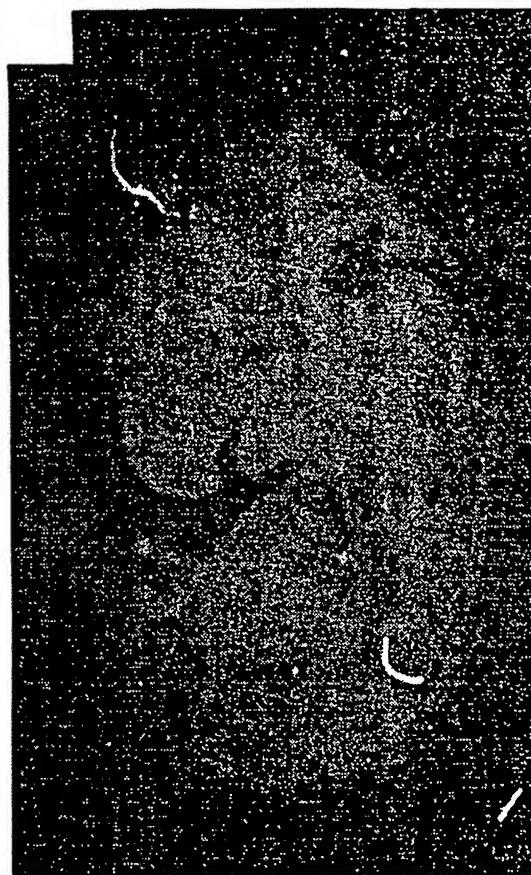


FIG. 3C

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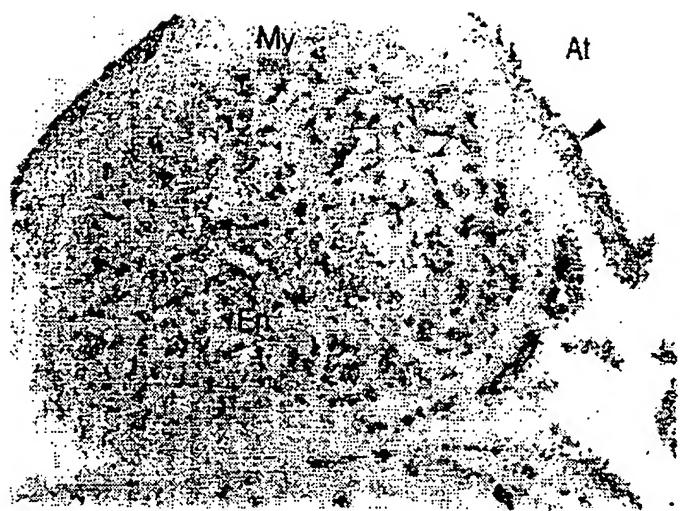


FIG. 4A

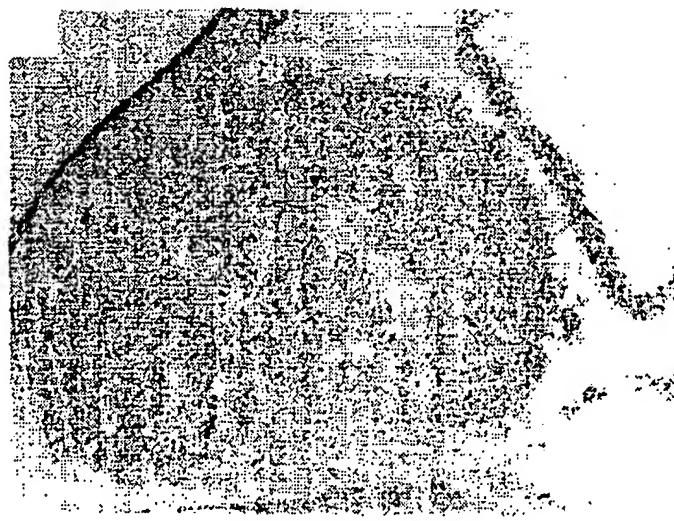


FIG. 4B

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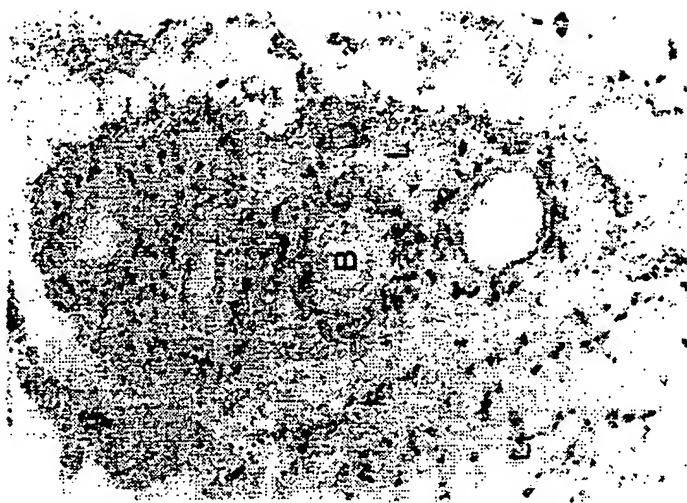


FIG. 4D



FIG. 4C

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FIG. 4E

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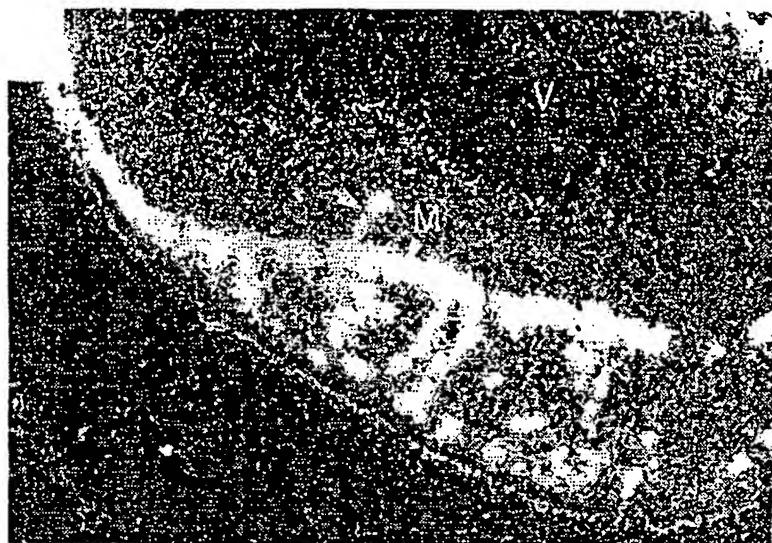


FIG. 5A



FIG. 5B

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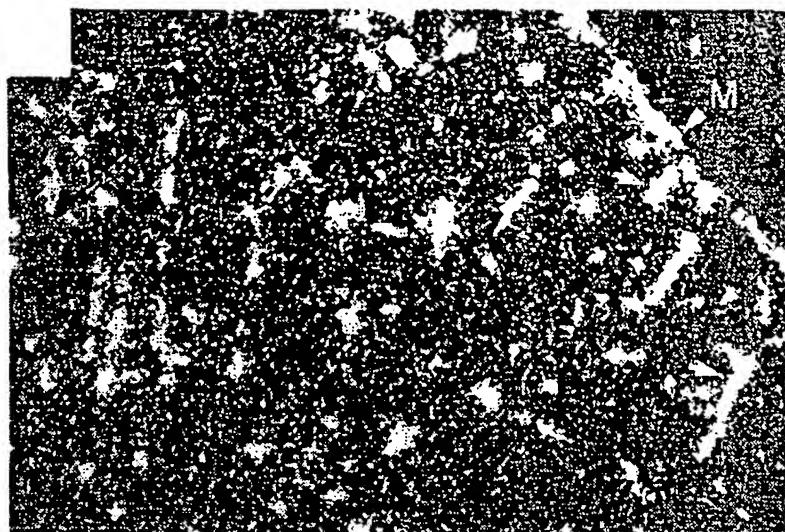


FIG. 5C

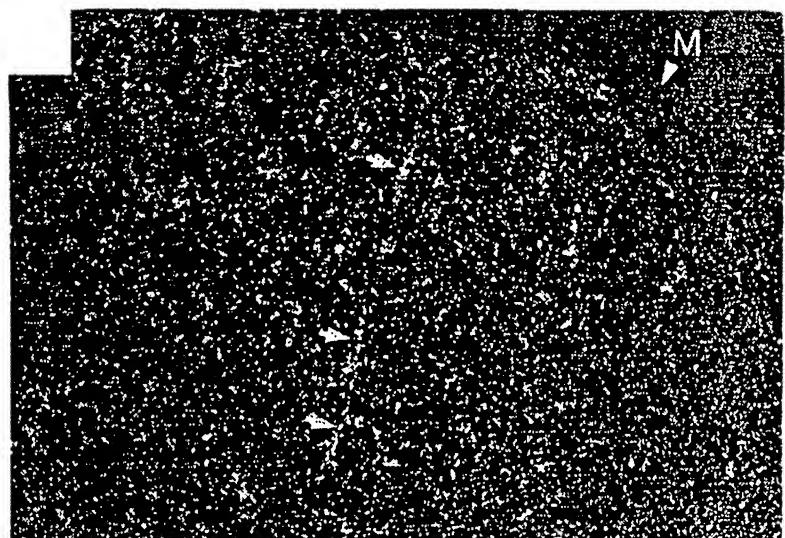


FIG. 5D

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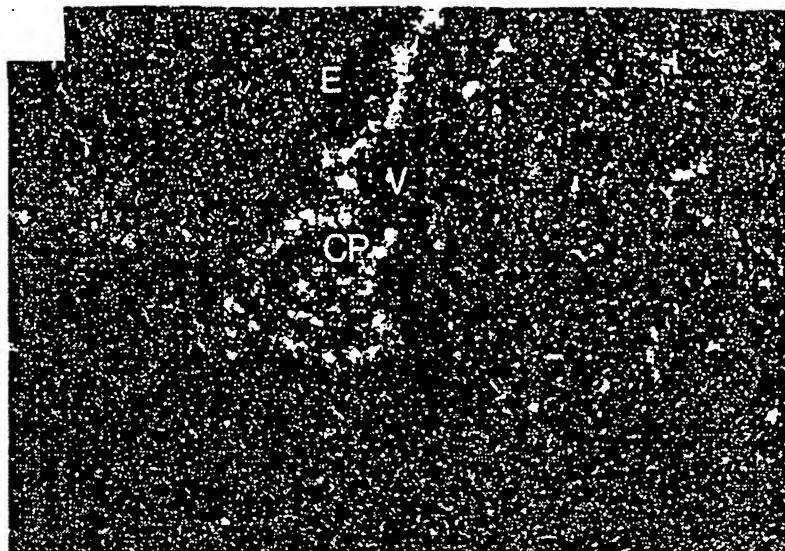


FIG. 6A

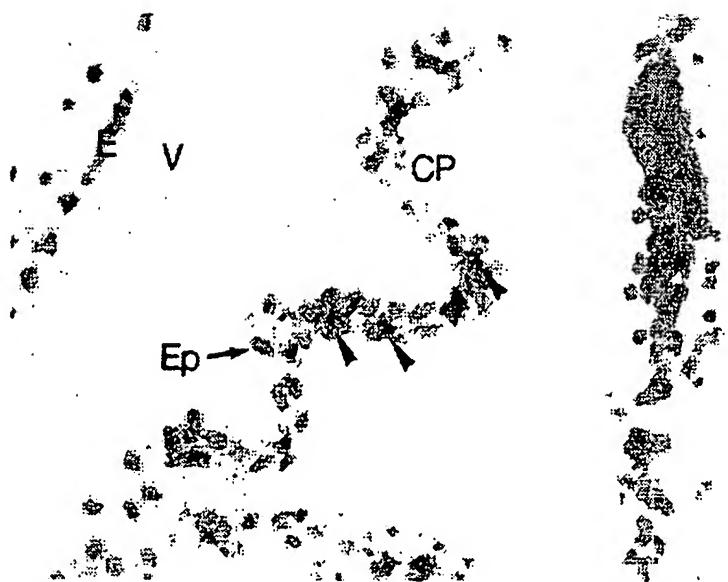


FIG. 6B

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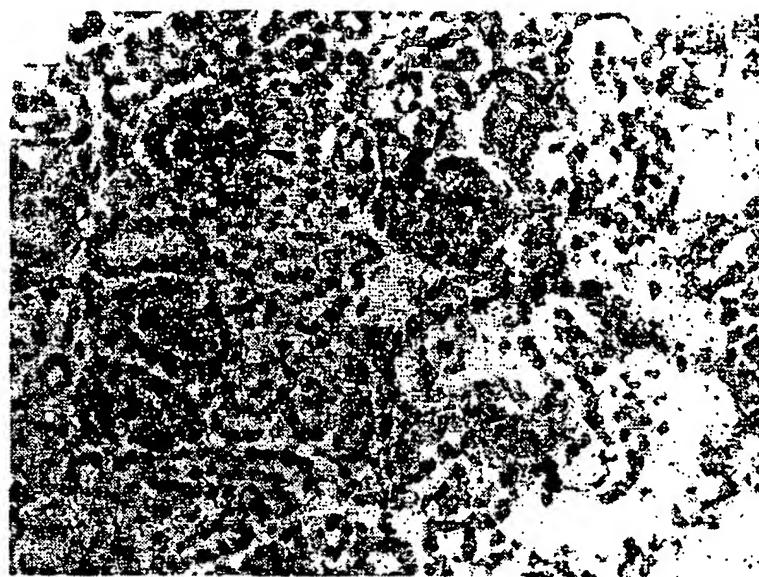


FIG. 7A

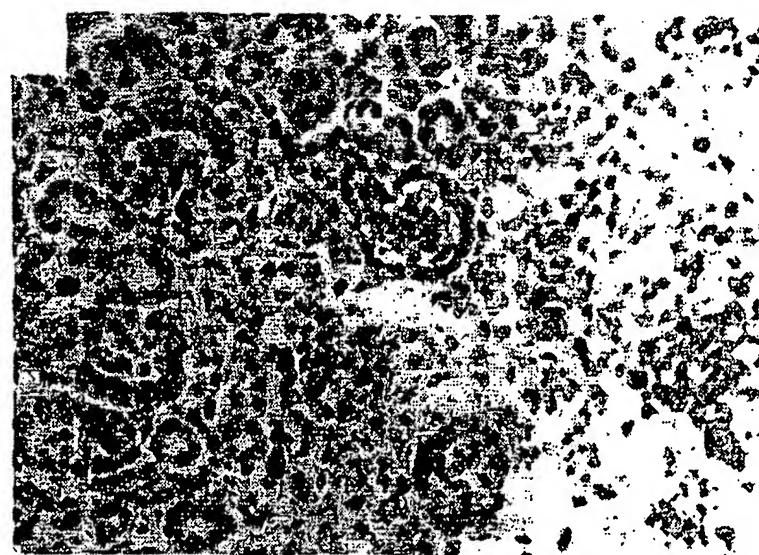


FIG. 7B

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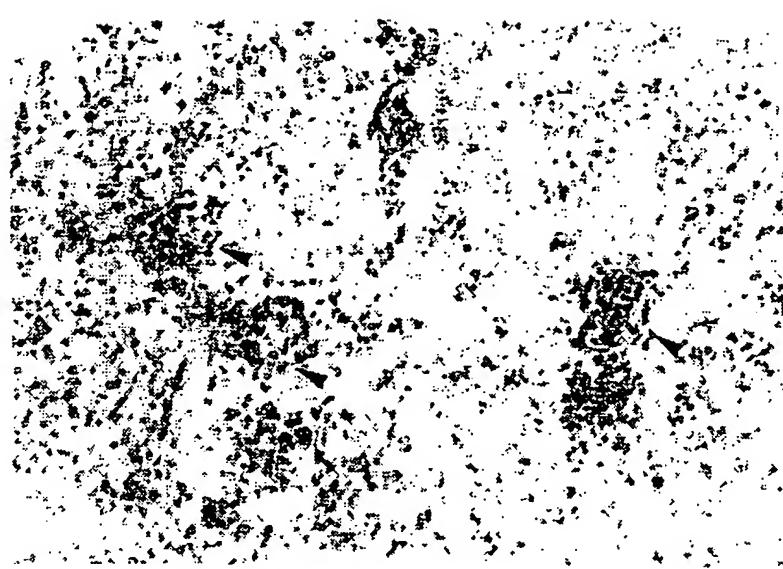


FIG. 7C

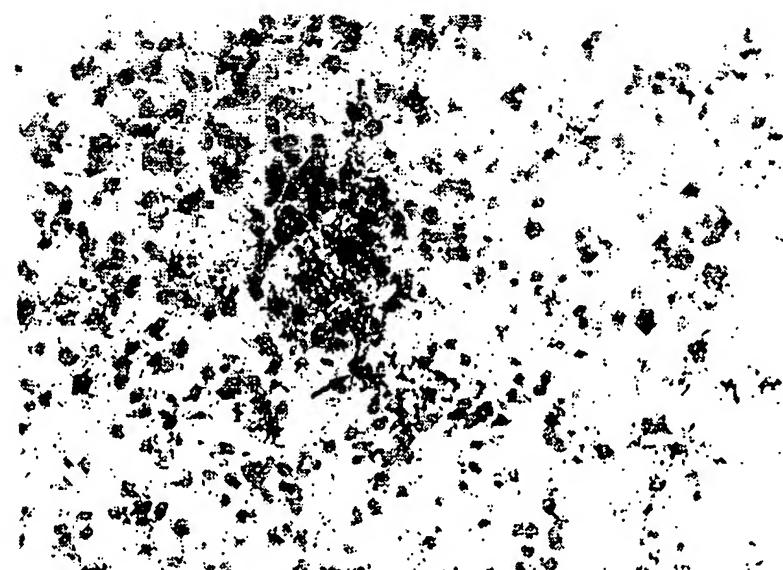


FIG. 7D

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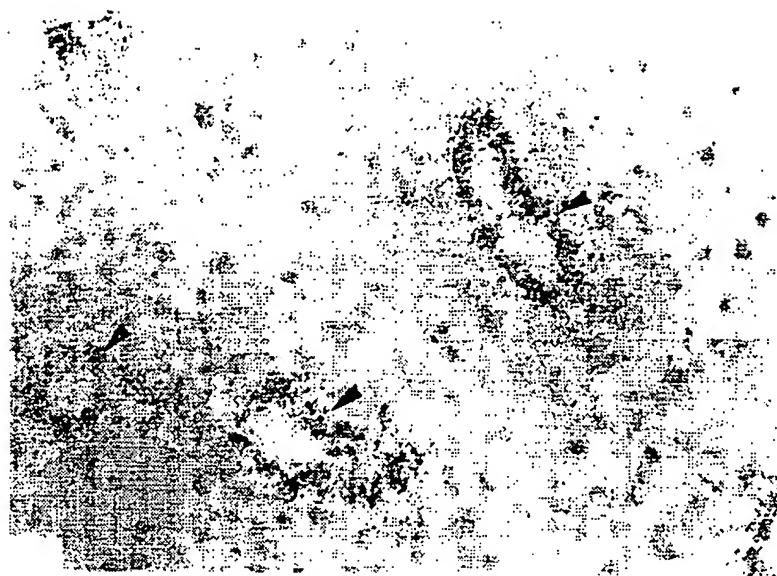


FIG. 8B

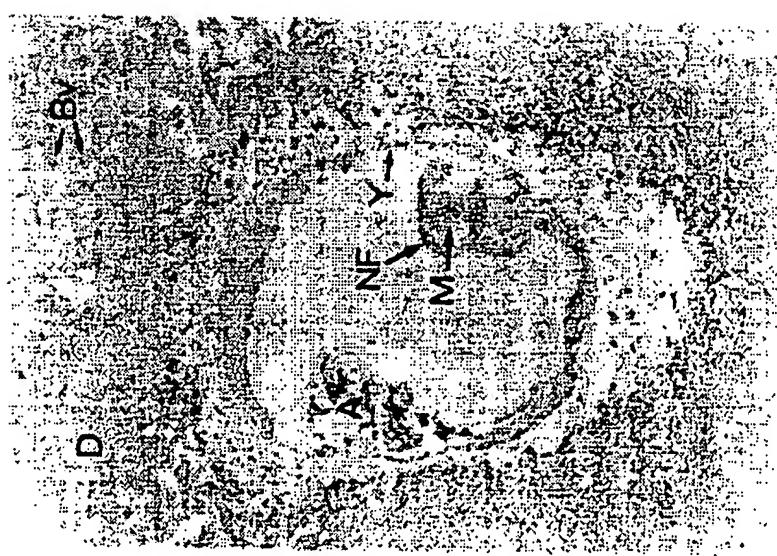


FIG. 8A

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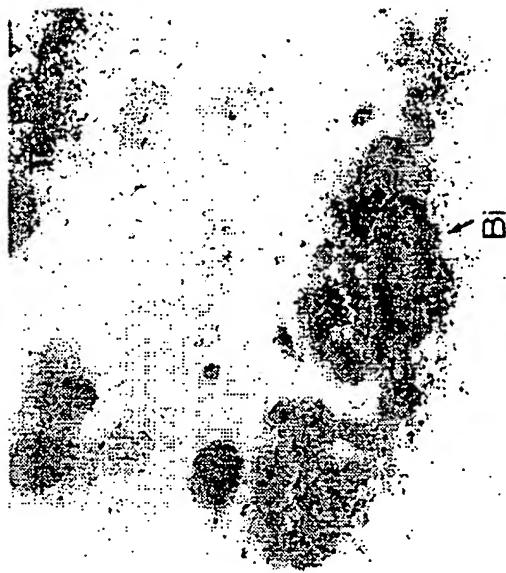


FIG. 8D



FIG. 8C

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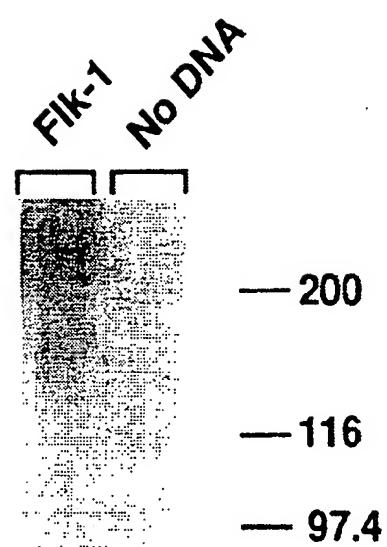


FIG. 9A

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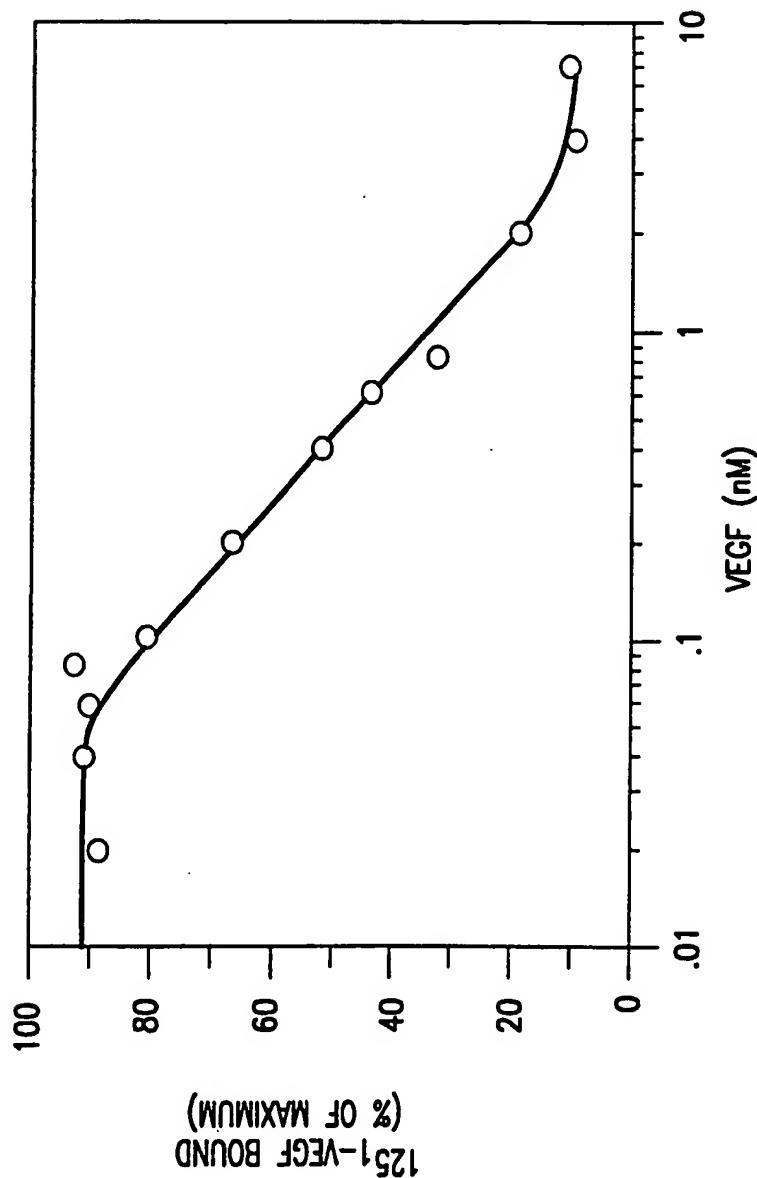


FIG. 9B

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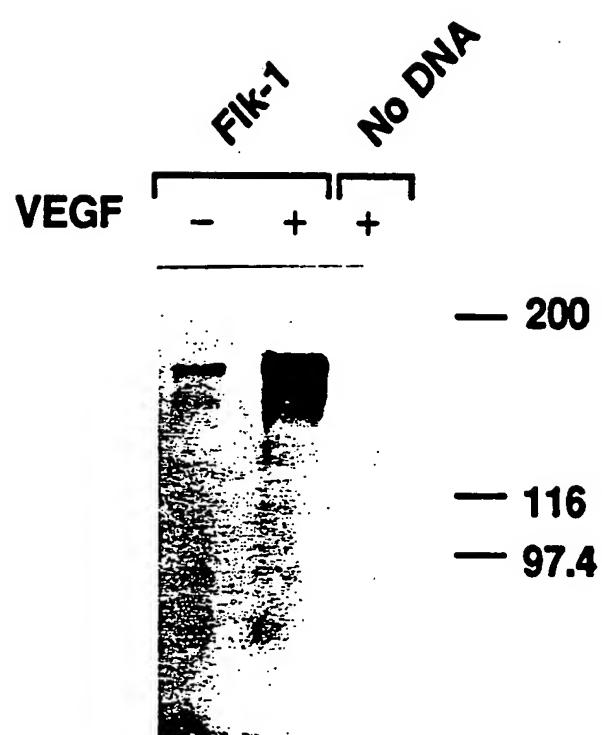


FIG. 10

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1 TATAAGGGCAATTCGCTACGGGACCCCCCTCGAGGTGAGCCTATCGATAACCTTCATATCGAATTCCCCCAGACACTGTGTCAGGGCAGC 90
 91 CGCGATAACCTCGCTGACCGGATTCGGGACACCGGCTGACACGGGGGGCTCGAGCGACGGGGGGCTGCGGGGGCTCTCGGGGCTCTCT 160
 181 GCGCTCGGGGGCCATACCGGCTCTGTACTTTCGCGGCCAGGGAGGAGGAGTCTGTGCGCTGAGAAACTCGGCTCTGTGCCCA 270
 M E S K A L L A V A L W F C V H T R A A S V G L T 25
 271 GCGGCCACGTCCACGGATGGAGACCAAGCCCTCGTAGCTGTGCGCTCTGTGGTCTGCGTGGAGACCGAGCGGGCTCTGTGGGTTGACT 360
 26 G D F L H P P K L S T Q K D I L T I L A N T T L Q I T C R G 55
 361 CGCGATTTCTCCATCCCCCAAGCTCAGCACACAGAAAGACATACTGACAATTTCGCAAATACAAACCGTCAGATTACTTCCAGGCGA 450
 56 Q R D L D K L M P N A Q R D S E H R V L V T E C G G G D S I 85
 451 CAGCGGACCTGGACTGGCTTGGCCAATCGTCAGCGTGAATCTGAGGAAGCGTATCGTGAATGAAATCGGCGCTCGTACAGTATC 540
 86 F C K T L T I P R V V G N D T G A Y K C S Y R D V D I A S T 115
 541 TTCTCCAAAACACTCACCATCCACGGTGGTCCGAAATGATACTCGACCTACAACTCGCTCTCGACTGACCCGACTCGACATACCGTCCACT 630
 116 V Y V Y V R D Y R S P F I A S V S D Q H G I V Y I T E N K N 145
 631 GTTTATGTCTATGTCGACATTACAGATCACCATTCATCGCTCTCGACTGACCCGATGGCATGTCATCACCCAGAACAGAAC 720
 146 K T V V I P C H G S I S N L N V S L C A R Y P E K R F V P D 175
 721 AAAACTGTGATGATCCCTGGCGAGCGCTCAATTCAAAACCTCAATCTGTCCTTGCCTAGCTACAGAAAGAGATTGTTCCGGAT 810
 176 C N R I S K D S H I G F T L P S Y W I S Y A G M V F C E A K 205
 811 CGAAACAGAATTCTGGACAGCGAGATGGCTTACTCTCCACCTACATGATCAGCTATGCGGCGATGGCTCTCTGTGAGCGGAAG 900
 206 I N D K T Y Q S I M Y I V V V V G Y R I Y D V I L S P P H H 235
 901 ATCAATGATGAAACCTATCAGTCTATCATGACATACTTGTGCTGACCGATATGGATTATGATGATGATTCTGACCCCCCGATGAA 990
 236 I K L S A G K K L V L N C T A R T E L N V G L D F T W H S P 265
 991 ATTGAGCTATCTGGCGAGAAAACCTGTGCTTAAATTGTACACGGAGAACACAGCTCAATGCGGCTTGATTTCACCTGGCACTCTCCA 1080
 266 P S K S H H K K I V N R D V K P F P G T V A K M F L S T L T 295
 1081 CCTTCAGACTCTCATCATAGAACATTGTAACCGGATCTGAAACCGCTTCTCGACTGCGGAGATGTTTGACCGACCTGACA 1170
 296 I E S V T K S D Q G E Y T C V A S S G R M I K R N R T F V R 325
 1171 ATAGAAAGTGTGACCAAGAGTGACCAAGGGATAACCCCTGTGACCGTCACTGGACCGATGATCAAGACAAATAGAACATTGTCCGA 1260

FIG.11A

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326 V H T K P F I A F G S G M K S L V E A T V G S Q V R I P V K 355
 1261 G T C A C A C A A A G C C T T T T A T T G C T T C C G T A C T G C C A T G A A A T C T T G C T G G A A C C C A C A G T G C C C A G T C A A G T C C G A A T C C C T G T G A A G 1350
 356 Y L S Y P A P D I K N Y R N G R P I E S N Y T M I V G D K L 385
 1351 T A T C T C A G T T A C C C A C C T C C T G A T A T C A A A T C G T A C A G A A T C C A A G G C C A T T G A C T C C A A C T A C A C A T G A T T G T G C C C A T C A A C T C 1440
 386 T I M K V T K R D A Q N Y T V I L T N P I S N E K Q S H M V 415
 1441 A C C A T C A T C C A A C T G A C T G A A A G C A T C C A G G A A C T A C A C G G T C A T C C T C A C C A A C C C A T T T C A A T G G A G A A C A G A C C C A C A T C G T C 1530
 416 S L V V V K V P P P Q I G E K A L I S P M D S Y Q Y G T M Q Y L 445
 1531 T C T C I G G T T G A A T G T C C C A C C C A C A T G C G A G A A G C C T T G A C T T G C T C O C C T A T G C A T T C C T A C C A G T A T G G C A C C A T G C A G A C A T T G 1620
 446 T C T V Y A N P P L H H I Q N Y N O L E E A C S Y R P G Q T 475
 1621 A C A T C C A A C T C T A C C C A A C C C T C C C T C C A C C A C A T C C A G T C G T A C T T G C C A C C T A C A G A A G C C T C C T A C A G A C C C C C C A A M C A 1710
 476 S P Y A C K E K R H V E D F Q G G N K I E V T K N Q Y A L I 505
 1711 A C C C C T A T G C T T G A A C A A T G G A G A C A C C T G A C G A T T T C C A C G G G G G A A A C A A G A T C C A A G T C A C C A A A A C C A A A T A T G C C C T G A T T 1800
 506 K G K N K T V S T L V I Q A A N V S A L Y K C E A I N K A G 535
 1801 G A A C G A A A A C A A A A C T G T A A G T A C C C T C C T G A T C A C C C T G C C A A C C T G T C A G G C T T G C C C A G C C A A C T G A G C C A T C A A C A A G C G G G A 1890
 536 R C E R V I S F H V I R G P E I T V Q P A A Q P T E O E S V 565
 1891 C G A C C G A G A G G C T C A T C T C C T T C C A T G T G A T C A G G G T C C T G A A A T T A C T G T G C A A C C T G C T G C C C A G C C A A C T G A G C A G G A G T G T G 1980
 566 S L L C T A D R N T F E N L T N Y K L G S Q A T S V H N G E 595
 1981 T C C C T G T G C A C T G C A G A C A G A A A T C C T T G A G A A C C T C A C G T G G T A C A A C C T T G G C T C A C A G G C A A C T C G G T C C A C A T G G G C G A A 2070
 596 S L T P V C K N L D A L N K L M G T M F S N S T N D I L I V 625
 2071 T C A C T C A C A C C A G T T G C A A G A A C T T C G A T G C T T T G G A A A C T G A T G G C A C C A T G T T T C T A C A C C A C A A T G A C A T C T T G A T T G T G 2160
 626 A F Q N A S L Q D Q G D Y V C S A Q D K K T K K R H C L V K 655
 2161 G C A T T I C A G A A T C C C T C T C C A G A C C A A C C C G A C T A T G T T T G C T C T C A G A T A A G A A G C C A A A G A C A T T G C C T C G T C A A A 2250
 656 Q L I I L K R M A P H I T G N L S N Q T T T I Q E T I H V T 685
 2251 C A G C T C A T C C T A G A C C G A T G C A C C C A T G A T C A C C G A A A T C T G G A G A A T C A G A C A A C A A C C A T T G C C G A G A C C A T T G A A C T G A C T 2340
 686 C P A S C N P T P N I T K F K D N E T L V E D S G I V L R D 715
 2341 T C C C C A C C A T C T G G A A T C C T A C C C A C A C A T T A C A T G T C T C A A A C A C A C A C C C T C T G A A G A G T T C A C C C A T T G T A C T G A G A G A T 2430
 716 G N R N L T I R R V R K E D G G L Y T C Q A C N V L G C A R 745
 2431 G C G A A C C G A A C C T G A C T A T C C C A C C G T G A G G A A G G A G C A T G C G A G G C C T C T A C A C C T G C C A G G C C T C G C A A T G T C C T T G C T G C C A A G A 2520

FIG.11B

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746 A E T L F I I E G A Q H K T N L E V I I I L V G T A V I A M F 775
 2521 G C G A G A C C T C T T C A T A A C A G C T C C C A C G G A A A C C A A C T T C G A A G T C A T T A C C T C T C C G A C T G C A G T G A T G C C A T G T C 2610

 776 F M L L L V I V L R T V K R A N H G K L K T G Y L S I V M D 805
 2611 T T C T G C C T C C T T C T T G T C A T T G T C T A C C G A C C T T A A C G G G C C A A T G A A G G G A A C T G A A G A C A G G C T A C T T G T C T A T T G T C A T G G A T 2700

 806 F D K L P L D H R C K E L P Y D A S K N E F P R D R L K L G 835
 2701 C C A G A T C A A T T G C C T T G C A T G A G C C T T G C A A C C T T G C T T A T G A T G C C A C C A A G T G C C A A T T C C C A G G A C C G C T C A A A C T A G G A 2790

 836 K F L C R G A F G Q V I E A D A F G I D K T A T C K T V A V 865
 2791 A A C C T C T T G C C C C C G G T C C T T C G C C A A C T G A T T G A C C C A G A C C T T T G C A A T T G C A A G A C A C C A C T T G C A A A A C A G T A C C G T C 2880

 866 K M L K E G A T H S E H R A L M S K L K I L I H I G H H L M 895
 2881 A A C A T T G A A A G G A G G A G C A A C A C A G G C A G C A T G A G C C T C A T G T C T G A A C T C A A G A T C C T C A T C C A C A T T G G T C A C C A T C T C A A T 2970

 896 V V N L L G A C T K P G G P L M V I V E F C K F G N L S T Y 925
 2971 G T G C T G A A C C T C T A G G G G C C T G C A C C A A G G G G G G G G C C T C T C A T G G T G A T T G T G G A A T T C T G C A A G T T T G G A A C C T A T C A A C T T A C 3060

 926 L E C K R N E F V P Y K S K G A R F R O G K D Y V G K L S V 955
 3061 T T A C C C C C A A G A C A A A T G A A T T T C T C C T A T A G G C A A A G G G G A C C C T T C C C C C A G G C A A G G A C T A C G T T G G G G A G C T C T C C G T C 3150

 956 D L K R R L D S I T S S Q S S A S S G F V K H K S L S D V E 985
 3151 G A T C T G A A A A G A C C T T G G A C A G C A T C A C A G C A G C A G A C C T C T G C C A C C T C A G G C T T T G T G A C C A A A T C C C T C A G T G A T G A C A G 3240

 986 K K K A S K K L Y K D F L T L K H L I C Y S F Q V A K G M E 1015
 3241 G A A G A G A A C C T C T G A A G A A C T G T A C A A G G A C T T C T G A C C T T G G A G C A T C T C A T C T G T T A C A G C T T C A G T G C C T A A G G C A T G G A G 3330

 1016 F L A S R K C I H R D L A A R N I L L S E K N V V K I C D F 1045
 3331 T T C T G C C A T C A A G G A A C T G T A T C C A C A G G A C T T G G A C C A A A C T T C T C C T A T C G G A A A G A A T G T G G T T A A G A T C T G T G A C T T C 3420

 1046 G L A R D I Y K D P D Y V R K G D A R L P L K K M A P E T I 1075
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 1076 F D R V Y T I Q S D V N S F G V L L N E I F S L G A S P Y P 1105
 3511 T T T G A C A G A C T A T A C A C A A T T C A G A G G A T G T G G T C T T C C C T G T G C T T C C C T C G G A A A T T T T C C T T A C C T T C C C T C C C A T A C C C T 3600

 1106 G V K I D E E F C R R L K E G T R M R A P D Y T T P E N Y Q 1135
 3601 G G G C T C A A G A T T G T C A G G A C T T G A A A G A C C A A C T G A A A T C C G G C T C C T G A C T A C A C T A C C C C A G A A A T G T A C C A G 3690

FIG.11C

SUBSTITUTE SHEET

FIG. 11D

SUBSTITUTE SHEET

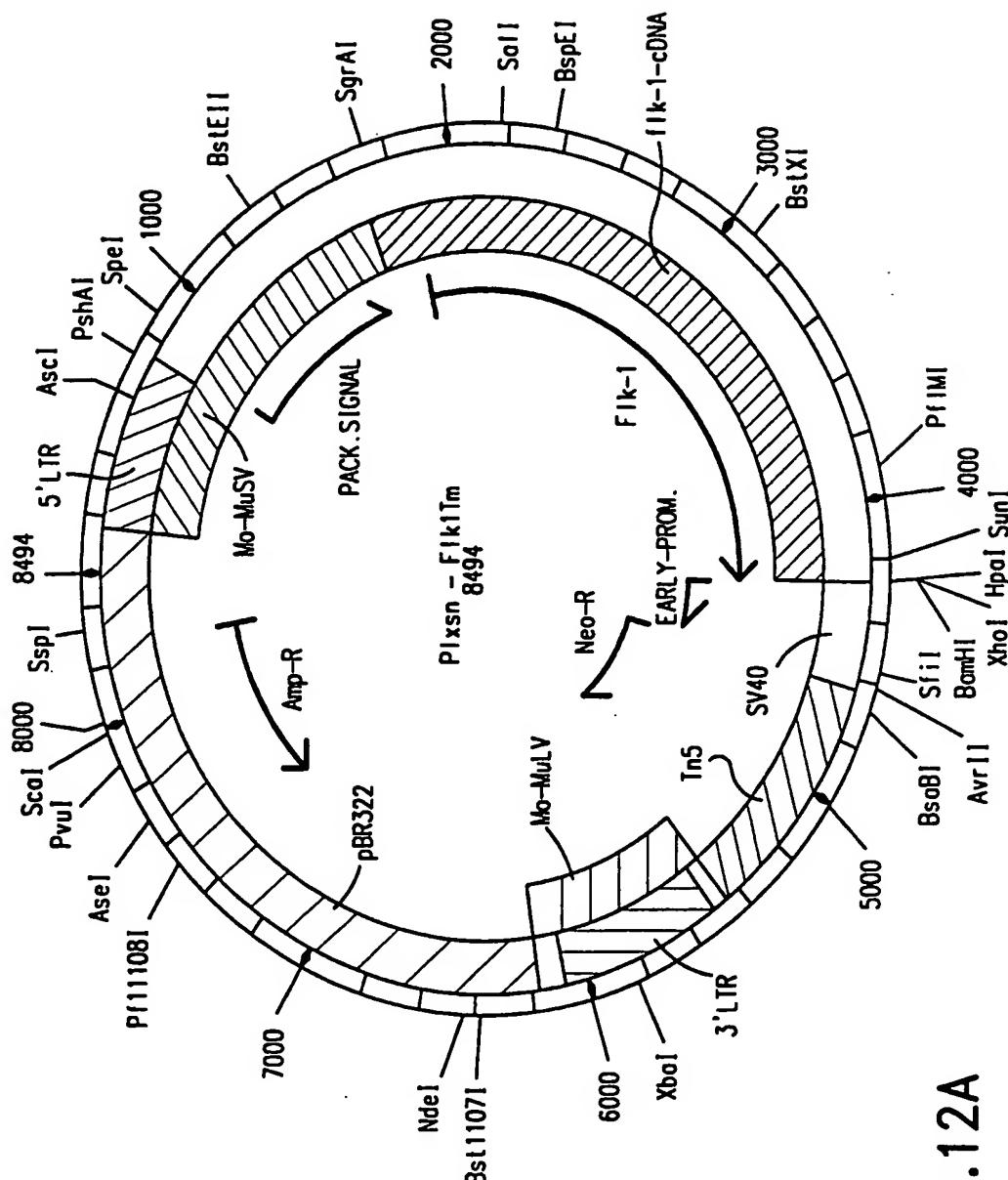


FIG. 12A

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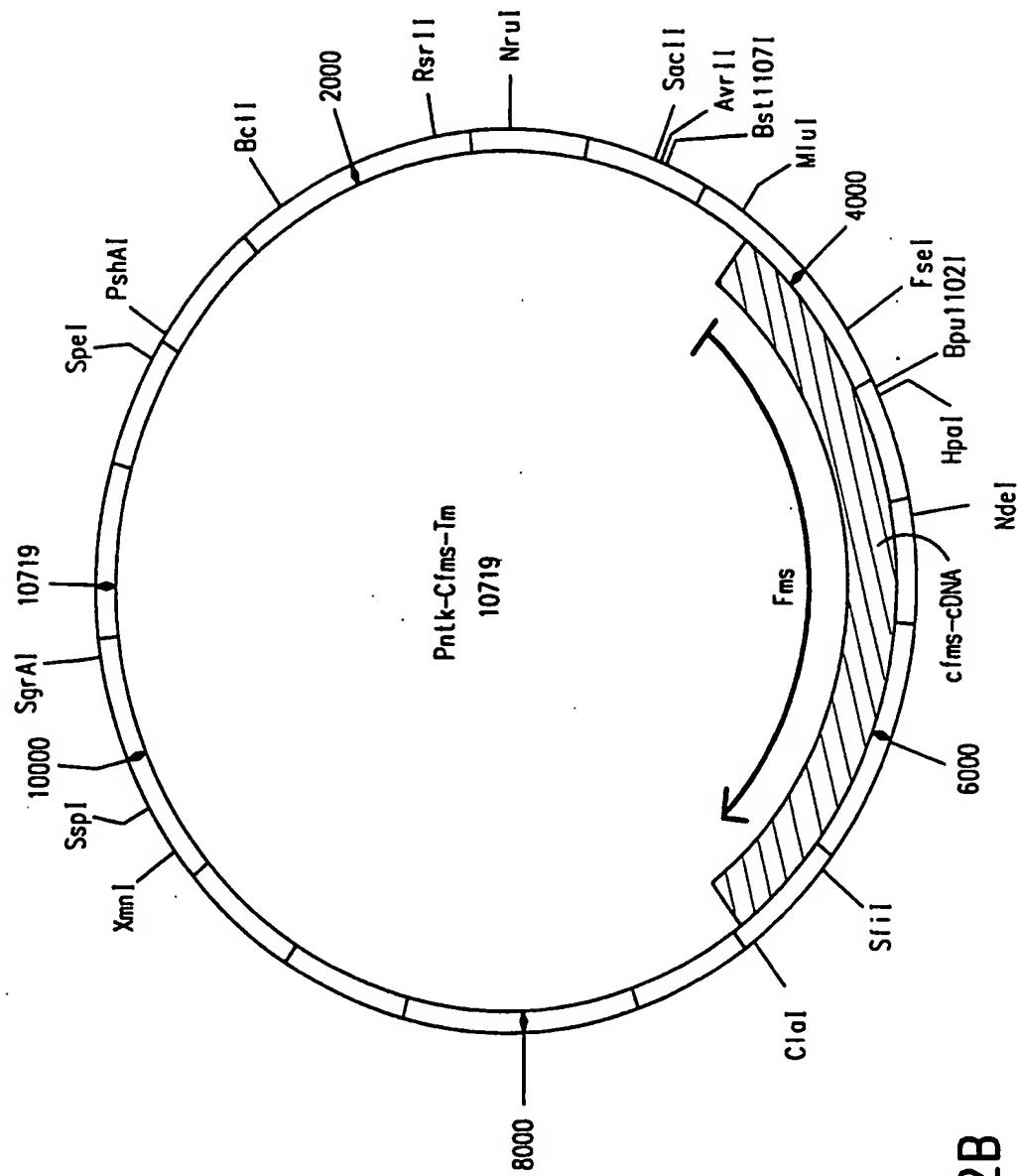


FIG. 12B

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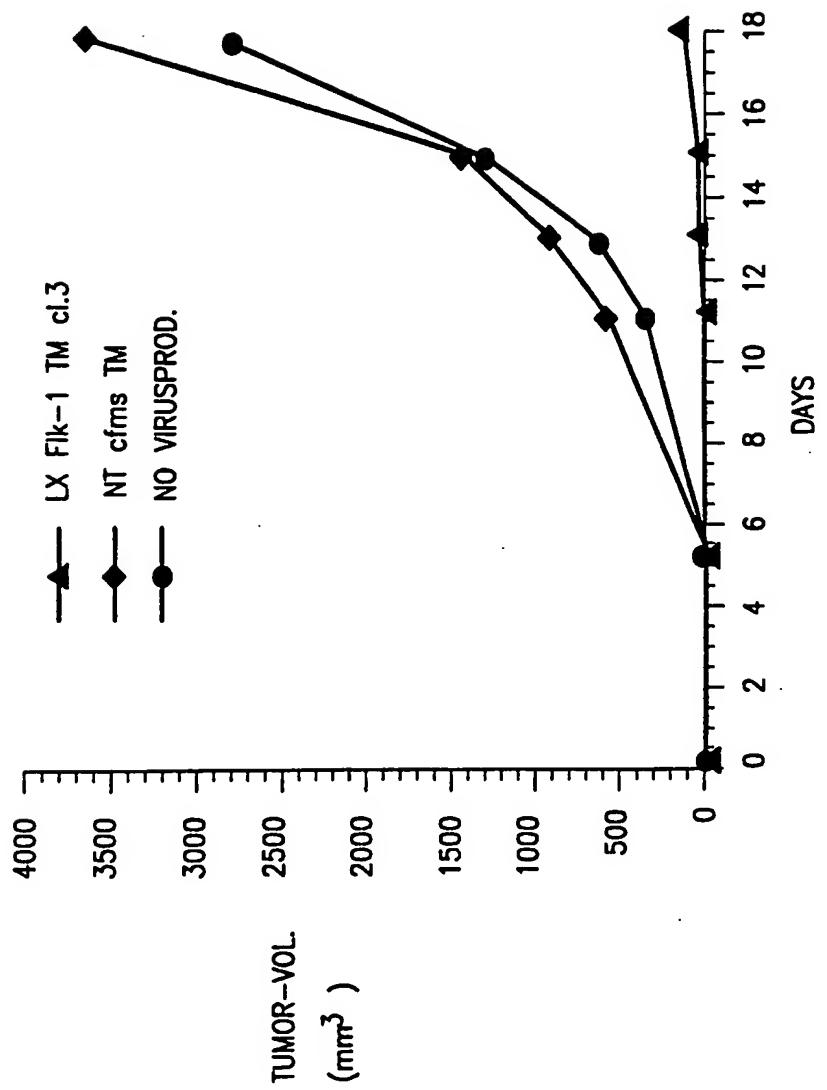


FIG. 13

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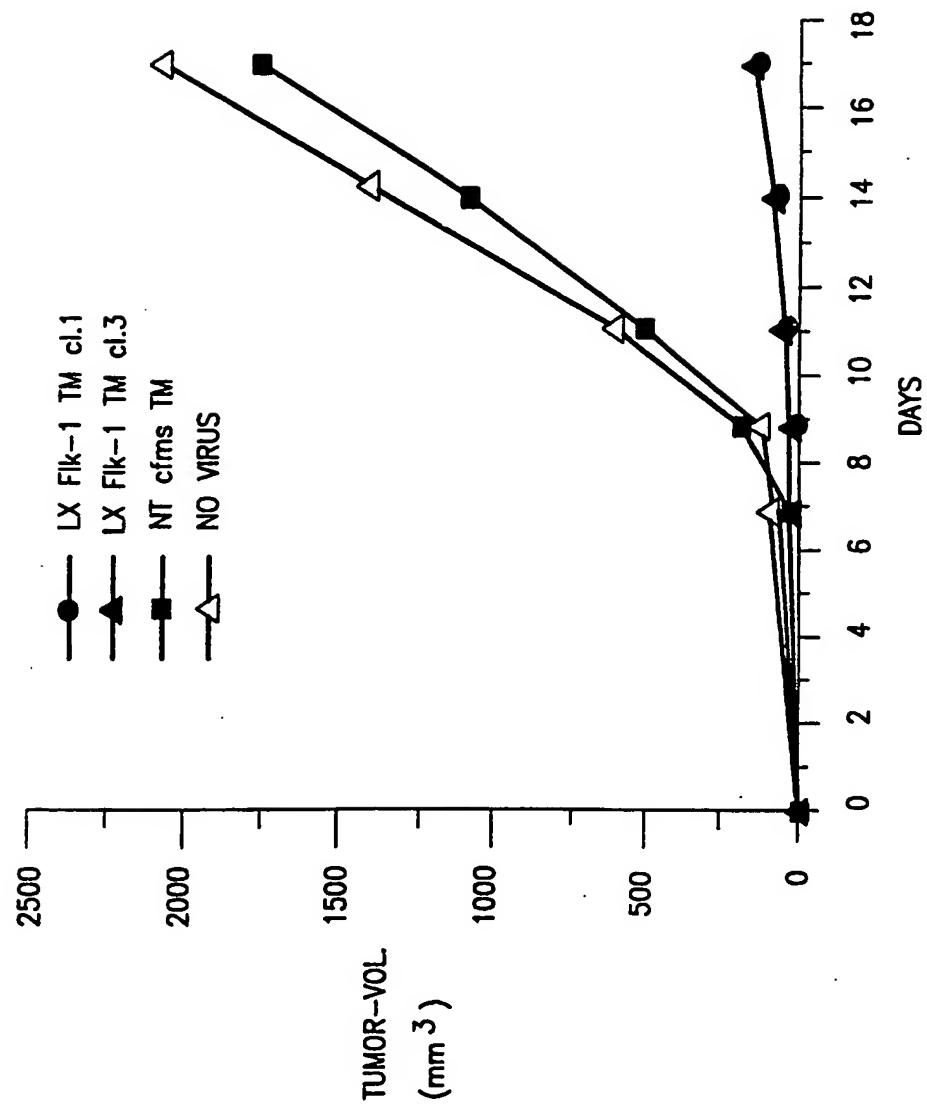


FIG. 14

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 93/03191

A. CLASSIFICATION OF SUBJECT MATTER

IPC 5	C12N15/12	C07K13/00	C12P21/08	C12N15/86	C12Q1/68
	G01N33/567	A61K37/02	C12N15/62		

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 C07K C12N A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF USA. vol. 88, October 1991, WASHINGTON US pages 9026 - 9030 MATTHEWS, W. ET AL.; 'A receptor tyrosine kinase cDNA isolated from a population of enriched primitive hematopoietic cells and exhibiting close genetic linkage to c-kit.' see the whole document ---	1-11
X	WO,A,92 17486 (TRUSTEES OF PRINCETON UNIVERSITY, US) 15 October 1992 see the whole document	1-11, 14-37
Y	see the whole document	12,13, 38,39,41

		-/-

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
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- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *a* document member of the same patent family

3

Date of the actual completion of the international search

Date of mailing of the international search report

11 March 1994

15 -04- 1994

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 93/03191

C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO,A,92 03459 (SLOAN KETTERING INSTITUTE OF CANCER, US) 5 March 1992 see the whole document ---	12,13
Y	BIOTECHNOLOGY vol. 3, no. 8 , August 1985 , NEW YORK US pages 689 - 693 MC CORMICK, D.; 'Human gene therapy : the first round' see the whole document ---	38,39,41
P,X	CELL vol. 72 , 26 March 1993 , CAMBRIDGE, MA US pages 835 - 846 MILLAUER, B., WIZIGMANN-VOOS, S., SCHNURCH, H., MARTINEZ, R., MOLLER, N.P., RISAU, W., AND ULLRICH, A.; 'High affinity VEGF binding and developmental expression suggest Flk-1 as a major regulator of vasculogenesis and angiogenesis.' see the whole document -----	1-43

INTERNATIONAL SEARCH REPORT

International application No.

PCT/EP 93/03191

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:
Remark : Although claims 25-28, 31-35, 43 are directed to a method of treatment of the human/animal body as well as diagnostic methods (Rule 39.1 (iv) PCT) the search has been carried out and based on the alleged effects of the compound/composition.
2. Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

The International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP 93/03191

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO-A-9217486	15-10-92	US-A-	5185438	09-02-93
		AU-A-	1924892	02-11-92
		CA-A-	2107463	03-10-92
		EP-A-	0580760	02-02-94
		WO-A-	9300349	07-01-93
		US-A-	5283354	01-02-94
		US-A-	5270458	14-12-93
		AU-A-	2296292	25-01-93
		AU-A-	3139493	15-06-93
		WO-A-	9310136	27-05-93
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WO-A-9203459	05-03-92	AU-A-	8510691	17-03-92
		CA-A-	2090469	28-02-92
		EP-A-	0546054	16-06-93